For Reference

NOT TO BE TAKEN FROM THIS ROOM

A FURTHER INVESTIGATION INTO THE ENGINEERING PROPERTIES OF MUSKEG

by

Capt. R.C. Wyld, RCE

Ex libris
universitatis
albertaensis

UNIVERSITY OF ALBERTA
QUAECUMQUE VERA

Digitized by the Internet Archive
in 2017 with funding from
University of Alberta Libraries

https://archive.org/details/furtherinvestiga00wyld

SYNOPSIS

The ever increasing demand for access by ground approach into Canada's north country and hitherto nearly inaccessible areas has made it essential that studies be carried out to increase the knowledge of the engineering properties of organic terrains, generally termed as muskeg.

This thesis is such a study, conducted by the author, under the direction of Dean R. M. Hardy of the Faculty of Engineering, University of Alberta.

The study consists of two parts. First is the development of a Vane Shear Test Apparatus employing the use of a Torque-wrench. Second is the collection of data on the measurement of in-situ shear strengths of different types of muskeg and its presentation showing the relationships between shearing strengths, depth, moisture content, ash content and angular deformation.

The Field Tests were conducted in the Pmbina Oil Fields which include large areas of different types of muskeg as classified by N. W. Radforth in his, " Suggested Classification of Muskeg for Engineers." (Bib #1.)

The results show that the maximum shearing strengths range from 115 to 850 pounds per square foot, that the shearing strengths increase, directly with depth, ash content and angular deformation and vary inversely with moisture content. The study shows that the Vane Shear Test Apparatus meets its design requirements.

Thesis
1958
#34

THE UNIVERSITY OF ALBERTA

A FURTHER INVESTIGATION OF THE ENGINEERING PROPERTIES OF MUSKEG.

A DISSERTATION
SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

FACULTY OF ENGINEERING
DEPARTMENT OF CIVIL ENGINEERING

BY
CAPTAIN RICHARD C. WYLD
ROYAL CANADIAN ENGINEERS.

EDMONTON, ALBERTA.

15 OCTOBER 1956

ACKNOWLEDGEMENTS

Acknowledgements are gratefully made to the Chief Engineer and to the Directorate of Military Training, Canadian Army, for the authorization of post graduate studies in the author's army career and for the provision of the necessary funds and time.

Acknowledgement is respectfully made to Dean R. M. Hardy and Associate Professor S. R. Sinclair whose personal interest and help enabled the author to complete the post graduate course.

Acknowledgement is made to the Research Department of Imperial Oil of Canada and to the Civil Engineering Department of Mobil Oil of Canada who gave valuable assistance in men, monies and materials thus providing field crews and transport for the collection of field data.

The author extends grateful thanks to Mr. I. C. MacFarlane of National Research Council for his continued help throughout the summer program of field work.

TABLE OF CONTENTS

page

Introduction 1

Theory, Development and Description of Vane Tester Apparatus 3

Field Tests 8

Observations and Results 12

Discussion of

- a) Vane Shear Tester Apparatus 14
- b) Results 15

Conclusions 25

Recommendations 26

Data Sheets 28

Computation Sheets 49

Plates 51

Bibliography 70

Appendices

- #1 Computation of Vane Sizes 71
- #2 Radforth Classification Table 72
- #3 Acker Drill Co. - Vane Tester Price list (1956) 73
- #4 Theoretical Calculations of Angular Twist in Drill Stems 74

INTRODUCTION

Although organic terrain or muskeg has many undesirable properties, the available strength of such terrains must be taken into account in the economic study of the construction of roads both permanent and short term in such areas.

This need has been brought about by the rapid increase in development in such terrain by the Department of National Defence, the Pulp and Paper Industries, the Oil Industry and the large Ore Development Programs. These expansions, necessitating the construction of roads and railways are concurrent across Canada.

The specific problems studied in this report are those of determining the Shearing Strengths of organic terrains by means of a Vane Shear Tester and corelating the strengths to depth, muskeg classification, moisture content, ash content, angular deformation and to determine the Liquid, Plastic and Shrinkage Limits obtained by laboratory tests.

The preliminary study involved the production of a Vane Tester using a Torque-wrench to apply the required torque. The Vane Tester was to be designed so that it was portable by

a crew of two or three men yet sufficiently strong to endure the wear and usages of field tests.

The area chosen for the field work was the Pembina Oil Fields, an area of approximately one thousand square miles, the northeast corner of which is located sixty-five miles west and twenty-five miles south of Edmonton, Alberta. It is estimated, by the Oil Companies in this area, that about thirty percent of this large tract is muskeg.

It is of interest to note some of the difficulties that arose and delays that occurred during the field tests. These were the existence of ice conditions in the muskeg until the end of June, and the time required to become familiar with the Oil Companies Expansion Programs. Numerous delays were caused by roads made impassible from inclement weather. The trial testing of the Vane Shear Test Apparatus was delayed until the last of June pending the arrival of the required torque-wrenches from the factory.

THEORY, DEVELOPMENT AND DESCRIPTION OF THE VANE TESTER APPARATUS

Essentially the Vane Test consists of pushing a vane, usually four bladed, into the ground and measuring the torque required to rotate the vane and thus shear a cylinder of soil. On rotation the vanes revolve a total cylindrical area equal to

$$2\pi r (h + r)$$

where h = length of vane

r = radius from centre line of shaft

The resisting moment to the torque applied is developed by the shearing strength of the soil acting on the revolved area of the vane. This can be stated as,

$$T = S \times A \times m$$

where T = Torque applied

S = Shearing strength of soil

A = revolved area of vane

m = moment arm. = radius of cylinder revolved.

Thus the necessary equation to compute the Shearing Strength of the soil from the torque applied may be stated as,

$$T = S \times A \times r \text{ .... Equation 1}$$

In order to make the vane penetrate to the required depth it is necessary to auger down to the desired depth less one half the length of the

vane. Due to this, the area on which the shear strength acts is the cylindrical wall area plus one end area.

Expressing Equation 1 in terms of radius and length of vane,

$$T = S\ (\ 2\pi r \times h \times r + \pi r^2 \times \frac{2}{3} r\ )$$

or $$T = 2\pi r^2 \times S\ (\ h + \frac{r}{3}\ ) \ \ldots\ldots\ \text{Equation 2}$$

where T = torque in foot-pounds

S = shearing strength in pounds per square foot

r = radius in feet

h = length of vane in feet.

To facilitate computations the height and radius of the vane were chosen such that the Shear Strength would be some whole integer times the torque applied. The radius of the vane was limited by the diameter of the portable field auger. After numerous trial computations the dimensions of the vane chosen were, diameter 4.5 inches and length 10.1 inches. Using a vane of these dimensions resulted in the shear strength being equal to the torque applied multiplied by five. Appendix number 1, page 70, shows the computations of Vane size.

From previous records of the shearing strengths of muskeg in Western Canada it was noted that in some instances strengths of over 1600 pounds per square foot were recorded. To ensure that the apparatus being developed would encompass such strengths, the torque

wrenches used had a range from zero to three hundred foot-pounds and could be used with an extension arm so designed that the actual torque applied was equal to two times the torque reading on the wrench. The manufacturers of the wrenches used, specified that the wrenches should not be stressed beyond eighty percent of their scale reading, which set a limit of two hundred and forty foot-pounds on a wrench. This meant that the extension arm would have to be used if shearing strengths of more than twelve hundred pounds per square foot were encountered.

To eliminate friction between the vane shaft and the soil being tested, the drill stem used as the shaft was enclosed in a thin wall casing of sufficient inside diameter to clear the drill stem couplings. The drill stem turned through a bearing at the bottom of the casing which was two inches above the top of the vane. Plans of the Vane Tester designed are presented on Plates 14, 15, 16, 17 and 18, pages 64 to 68, of this report.

The Vane Tester Apparatus designed and used in the Field Tests consists of:

2 - 300'# torque wrenches with 3/4" drive head
1 - extension arm, multiplication factor of 2
1 - Vane assembly, diameter 4.5", length 10.1",
    complete with thrust bearing and casing,
    overall length 2'-0" to centre of vanes.

2 - 5/8" pony drill rods, 2' long

4 - 5/8" pony drill rods, 4' long

2 - 2' lengths 1-3/4" casing complete with couplings

4 - 4' lengths 1-3/4" casing complete with couplings

1 - torque drive head fitted with 3/4" socket

1 - Casing Anchor complete with set screws

1 - Rotational strain gauge graduated to 1 degree

2 - Pipe wrenches 18"

2 - 5/8" pony drill stem coupling wrenches

1 - crescent wrench 6"

1 - Field auger kit, 6", complete with extension rods

1 - Working Platform, 2 pieces 4' x 4', 3/4" plywood

1 - Shovel LH

1 - Axe hand

1 - hammer sledge, 7#

The Vane Shear Test Apparatus produced was jointly designed by Mr. J. P. Walsh of Pembina Branch, Mobil Oil of Canada and the author. Mobil Oil provided the materials, workshop and labor for the production of the apparatus and the manning of the field crew. Mr. Walsh gave freely of his time, advice and help throughout the time spent in the field.

The Vane Test Apparatus produced is a modified version of the Vane Tester developed by Captain S. Thomson which is described in his Thesis, Bibliography 2.

The primary modifications made to the Thomson apparatus are as follows:

In the Walsh-Wyld apparatus torque is applied directly to the vane shaft by means of a Torque-wrench from which the applied torque can be read. In the Thomson model torque was applied by means of tensioning a steel wire, by winding on a hand ratchet, through a mechanical system including a spring anchored pulley and the wire being wound around a 20 inch diameter disc which was clamped by set screws to the vane shaft. To determine the torque applied involved the computation of the extension of the spring anchoring the pulley and then reading the applied torque and the shearing strength from a graph giving the relationship between these. The Walsh-Wyld apparatus is so designed that the shearing strength is equal to five times the torque reading.

The physical differences betwen the two models is most apparent by a study of the plans included in this report and in Thomson's thesis.

FIELD TESTS

The field tests were conducted in the Pembina Oil Fields and with the exception of one site were all carried out within the leaseholds of Mobil Oil of Canada. A photographic copy of the site plan showing the test areas is included in this report as Plate No. 19, Page 69.

Trial Tests to establish procedure and to correct any flaws in the apparatus were conducted in Block 3 as this was the earliest accessible area.

It was found during the trial tests that it was not possible to push the vane through the surface mat due to its very fibrous and rooty nature. It became standard procedure to remove the top three or four inches of the mat and to take the initial reading for each test hole at a depth of one foot. The next reading was taken at a depth of two feet and consequent readings taken at two foot intervals to the bottom of the muskeg.

All holes were augered to such a depth that when the vane was inserted, the centre of the vane was at the required depth and the top of the vane was one inch below the bottom of the augered hole.

Torque was applied to the vane at a steady rate of approximately thirty degrees per minute. This rate of deformation was adopted after trial

tests showed that if torque was applied by hand at a slower rate its application became uneven and jerky. In order to maintain some consistency the torque was applied by the same person for all readings.

At any given location, tests were run to give data on virgin muskeg, muskeg affected by drainage and muskeg consolidating under the well site pads which were constructed for drilling operations. To ensure that fairly representative data were obtained three tests were run for each condition of muskeg at each site. Many test holes had to be abandoned because logs, large roots or boulders were encountered during augering.

Throughout the program difficulty was experienced in obtaining good samples for testing in the laboratory. Augering greatly disturbed the material and the removal and inserting of the auger caused a large amount of sloughing from the sides of the hole. To keep the samples as representative as possible they were taken from the bottom portion of the load in the auger. All attempts to obtain good Shelby Tube samples were failures and samples retained were greatly disturbed. The use of three and one half inch diameter tubes still resulted in very compressed samples with a large reduction in water content. For three feet of muskeg in-situ the

the samples obtained were about eleven inches in length. The samples retained were kept by Mr. I. C. MacFarlane for laboratory investigation at National Research Council, the results of which will not be available before the summer of 1957.

Muskeg Classification was done by the method as described by Dr. N. W. Radforth in his paper, " Suggested Classification of Muskeg for the Engineer." This system is based on the classification of the living organic material at or on the surface of the terrain under consideration. This living organic material, known as coverage, is the first thing noticed as an observer enters the muskeg area. No knowledge of the species of plants is necessary to classify by this method. The Classification is done by recognition of the physical aspects of the growth including such things as, the woody or non-woody characteristics, the approximate height of growth, whether the growth is young, old or dwarfed, if the coverage is of tree or scrub form or grass like, or if growth is in patches, mats or hummocks.

A table, giving the summary of properties designating nine pure coverage classes, is presented as Appendix Number 2, Page 71, to this report.

Vane Tests were conducted at Well Site No. 28-8, of Mobil Oil Block 4, as recorded on Data Sheet No. 8, Page 35. These tests were run on virgin mus-

keg. On the information from Mr. J. P. Walsh, that the construction pad of clay fill was to be built at this site within a few weeks, four settlement gauges of the Casagrande pattern were installed. These gauges were placed at the surface and bottom of the muskeg and at two intervening levels. Mr. Walsh, of Mobil Oil, kindly consented to keep the record of settlement of these gauges.

It is noted that about seventy percent of the time when the vane was withdrawn after a test, the revolved cylinder of soil adhered to the vane. It was noted by the author and Mr. I. C. MacFarlane that the diameter of the cylinder of soil as accurately as could be measured was the same as the diameter of the vane.

OBSERVATIONS AND RESULTS

The following Data Sheets, Computation Sheets, Tables and Plates are presented as part of this report. As all Data Sheets are straight forward no sample computations are included.

Data Sheets nos 1 to 9, pages 28 to 36, present the Field Data with accompanying remarks and field sketches.

Data Sheet no. 10, page 37, records the Moisture and Ash Content Determinations of twenty-three tests run in the Soils Laboratory, University of Alberta, on disturbed samples taken in the field.

Data Sheets nos. 11 to 19, pages 38 to 46, record the data for the Atterberg Limits determinations.

Data Sheet no. 20, page 47, lists the Angular Deformations recorded for torques varying from 40 to 160 foot-pounds on lengths of 5/8 inch drill stem from 4 to 24 feet in length.

Data Sheet no. 21, page 48, is the summary of results of the Atterberg Limits Tests.

Computation Sheets nos. 1 and 2, pages 49 and 50, show the computation of the corrected angular deformations in the soil.

Plates nos. 1 to 4, pages 51 to 54, present graphs of shearing strength versus depth.

Plates nos. 5 to 8, pages 55 to 58, present the relationships between shearing strengths, moisture contents, ash contents and depths.

Plate no. 9, page 59, shows the position on the Plasticity Chart of some of the Muskegs tested.

Plates nos. 10 and 11, pages 60 and 61, present graphically the relationship between Angular Deformation and Depth for DFI and BDI Muskeg.

Plate no. 12, page 62, presents the relationship between Maximum shear strength versus Angular Deformation for BDI and DFI muskegs.

Plate no. 13, page 63, is the graphical presentation of Data Sheet no 20, page 47.

Plates nos. 14 to 18, pages 64 to 68, are the detailed drawings of the Walsh-Wyld model of the Vane Shear Test Apparatus.

Plate no. 19, page 69, is the Plan of the Areas within the Pembina Oil Fields where the tests included in this thesis were conducted.

DISCUSSION

The discussion is divided into two parts,

a) Discussion of the Vane Shear Test Apparatus,

b) Discussion of the results.

Discussion of the Vane Shear Test Apparatus

Mechanically the Vane Tester developed and used was found very satisfactory. The addition of guide bearings at regular intervals, say every second casing section, would eliminate the small transverse movement of the vane shaft within the casing. This could easily be done by use of tapered split bronze bushings, machined to fit between the vane shaft and the inside of the casing couplings. The weight of the tester, especially when assembled to a length of ten feet or over, made it quite awkward to handle. This could be remedied by the use of a smaller diameter high strength steel vane shaft and a lightweight metal for the casing. This would also reduce the overall weight of the tester which was not as easily portable as desired. To transport the apparatus from the vehicle to the test site required six well loaded trips by one man.

It is worthy of note, that just when the construction of the Vane Tester designed had been finished and the test trials and necessary adjustments made, that a commercial Vane Shear Kit was put on the market by Acker Drill Company Incorporated of Scranton, Pennsylvania.

The Acker kit includes three sizes of vanes, two torque wrenches of 150 and 600 inch-pounds capacities and guide bearing and couplings as required. The largest vane in the Acker Kit has a diameter of 3.63 inches as compared to the 4.5 inch diameter vane used in this project. The Acker Kit is practically the same as the apparatus developed by Mr. J. P. Walsh of Mobil Oil and the author. A summary of the component parts and the price list of the Acker Kit is included in this report as Appendix Number 3, page 72.

As a small sized vane was not used during any of the field tests, the author does not feel qualified to comment on any merits or demerits of smaller equipment. It is his opinion however that a Tester using small sized vanes would likely give comparable results. Smaller apparatus would also increase the portability of the equipment and greatly reduce the physical effort required during the operation of the field tests.

Discussion of Results

Perusal of plates numbers 1 to 8, which graphically present the correlation of some of the engineering properties of muskeg, shows the following characteristics.

a) For Muskeg of Radforth Classification DFI

  i Virgin muskeg shows an increase in strength with depth varying from 270 to 390 pounds per square foot and having a characteristic decrease in strength just below mid-depth with the minimum strength recorded at this point.

  ii Muskeg, which has been drained for 21 months, shows an increase in strength with depth, ranging from 285 to 475 pounds per square foot. The characteristic decrease in strength occurs between 0.2 and 0.4 of the total depth when the muskeg is on the virgin side of the drainage ditch. Where the tests were run between the overburden and the drainage ditch, the characteristic fall-off in strength occurs between 0.4 and 0.8 of the depth.

  iii The muskeg consolidated under 400 pounds per square foot for twenty-one months, shows no tendency to increase strength with depth, but it shows again the fall-off of strength at 0.4 to 0.6 of the depth with a minimum of 500 pounds per square foot, the maximum strength recorded for this condition being 700 pounds per square foot.

In summary DFI muskeg shows a general increase in shearing strength with depth, with a characteristic weak zone at 0.4 to 0.6 of the depth with minimum

values of 270 pounds per square foot in virgin muskeg to 500 pounds per square foot under consolidating conditions.

Plates, nos.5, 6 and 7, which present graphically the correlations from DFI muskeg, between shearing strength, depth and moisture and ash contents, show that the Shearing Strength increases,

i with increase in depth
ii with decrease in moisture content
iii with increase in ash content.

Ash content was determined from weight of residue after 24 hours at 300°C divided by: dry weight of sample after 24 hours at 110°C.

The plates also indicate an increase in Ash content with depth and a decrease in Moisture content with depth. The consistency with which increase in the shearing strength is accompanied with a decrease in moisture content is clearly shown by graphs a and b on plate 5.

b) For muskeg of Radforth Classification BDI.

The following points are clearly depicted on plates 2, 3 and 8, which present the correlations of some of the engineering properties of BDI muskeg. It is noted at this point that some of the Field Data sheets show the classification as A to BDI, which is applying the Radforth classification beyond its intended degree.

In presenting the data in graph form the author has included all A to B DI classes as strictly BDI and feels justified in doing so as the A class growth tends to overshadow the B class growth in visual identification due to its height and more noticeable foliage during the summer season.

i Virgin muskeg shows the shearing strength to increase directly with depth. BDI muskeg does not show the pronounced characteristic of having a zone from 0.4 to 0.8 of the depth which has a decrease in strength. Rather it shows a slight increase in strength through this zone and a marked increase in strength below this depth. Strengths vary from 175 to 525 pounds per square foot at one location and from 150 to 575 pounds per square foot at another location, both being in the same large BDI muskeg area.

ii Muskeg affected by drainage increases in shearing strength directly with depth, with variations from 325 to 525 pounds per square foot from the surface to the bottom of the muskeg. Test run on the cleared Flowline right of way show strengths from 115 to 450 pounds per square foot which are a little lower than the strength ranges found in the virgin muskeg.

iii The plotted data from both locations show a slight decrease in strength with depth for BDI muskeg under an overburden of about 320 pounds per square foot for a period of ten months. One site shows a decrease from 550 to 500 pounds per square foot from surface to bottom and the second location shows a decrease from 600 at the surface to 375 at mid-depth increasing to 550 pounds per square foot at the bottom. In summary BDI muskeg, in the virgin and affected by drainage states, shows the shearing strength increases directly with depth, while under the overburden existing at the site, this type of muskeg shows a small decrease in shearing strength with increase in depth.

Plate 8, presenting the relationships between shearing strength, depth and ash and moisture content for virgin muskeg shows that moisture content decreases with an increase in shearing strength and depth. Ash content with depth remains nearly constant except for the bottom few inches of muskeg where the ash content shows a sharp increase. The data was not comprehensive enough to show any characteristic for shearing strength versus ash content.

c) For muskeg of Radforth Classification ADI and

Plate 4 shows shearing strength versus depth for both ADI and C class virgin muskeg. As construction had not been started it was not possible to obtain further data at the sites.

The ADI muskeg shows minimum strengths varying from 275 to 475 pounds per square foot from the surface to the bottom. It is at this site that settlement gauges previously mentioned have been installed.

Data were obtained for the type C muskeg as it was the only area encountered where there was only a single descriptive type of muskeg. The surface mat was extremely tough and axe work was required before the vane could be pushed through to the one foot depth. After the bottom of the muskeg was reached at two and one half feet from the surface, augering continued as local lore had suggested the depth being somewhere between "very deep" and "bottomless". As data sheet number 9 records clay extended on down to a depth of eleven and a half feet, from the surface, at which point augering was stopped. Plate 4, graph (b) shows that for this type muskeg the shearing strength increases directly with depth over the range of 550 to 765 pounds per square foot for an increase in depth of one foot.

The data and computations recorded in the determination of moisture and ash contents for

twenty-three disturbed samples are presented on Data Sheet No 10, Page 37.

In an attempt to analyse the plasticity characteristics of muskeg, tests to determine the Atterberg Limits were conducted on nine disturbed samples. Data Sheets numbers 11 to 19, pages 61 to 69,record the test data and computations. A summary of the results is compiled as Data Sheet number 21, page 48. A study of this summary leads to the following discussion.

The increases and decreases in the Liquid Limit parrallel the natural moisture content and the highest values of moisture content and liquid limit occur at the lowest ash contents.

The Plastic Limits determined are in all but two cases higher than the liquid limits. In the two cases where the liquid limit is greater than the plastic limit the samples have a high ash content. From the tests run it is noted that when the ash content is over 50% the plasticity index can be computed. At an ash content of 37% the liquid and plastic limits are nearly equal giving a plasticity index of zero. Time did not permit but it might prove interesting to make a further study to see if 35% to 40% ash content is a limit below which the plasticity index can not be computed.

In performing the tests difficulties were

found in running the plastic and shrinkage limits. Due to the very fibrous organic nature of the samples the water content had to be very high in order to roll the soil into threads of approximately one-eighth inch in diameter. The few results obtained are plotted on the Plasticity Chart presented as Plate no. 9, page 59. The determination of the shrinkage limits was not continued throughout all the tests as measurement of the volume of the dry pats could not be done accurately.

During the field tests the total angular deformations for all torques were recorded on the applicable field data sheets. These angular deformations included the twist of the drill stem as well as the deformation of the soil. In order to know the deformation of the soil only, it was necessary to determine the amounts of twist in the drill stem for variations in lengths and applied torques.

By securing the blades of the vane in a vise and measuring the angular twist in the drill stem for applied torques of forty, eighty, one hundred and twenty and one hundred and sixty foot pounds the data as presented on Data Sheet no 20, page 47, were obtained. These data are presented graphically on Plate 13, page 63.

The determinations of the angular deformations

in the soil are shewn on Computation Sheets nos 1 and 2, pages 49 and 50, which are self-explanatory. For these computations the twist in the drill stems was determined from the graphs on Plate 13.

A brief discussion on the Theoretical Computations of twist in the drill stem is presented as Appendix no 4, page 73, to this study.

Plate no 10, page 60, shows the Angular Deformation versus Depth for DFI Muskeg in the three states of virgin, drained and drained and consolidated under a load of approximately 400 pounds per square foot for twenty-one months. In general there appears to be a decrease in angular deformation with increase in depth down to the six foot depth. The data presented are not conclusive.

Plate no 11, page 61, presents similar data for BDI Muskeg. Again there appears to be a decrease in angular deformation with increase in depth down to the six foot depth. BDI muskeg shows a tendancy to increase in angular deformation between the six and eight foot depth zone. This may be due to the higher mineral content near the bottom of the muskeg.

From the data presented on Plates 10 and 11 both the DFI and BDI muskegs show a tendancy to decrease in angular deformation with an increase in depth.

Plate no. 12 graphically presents maximum Shear Strength versus Angular Deformation for BDI and DFI muskegs. The data presented is not conclusive but show that both types tend to increase in shear strength with an increase in angular deformation as shewn by the sloped dashed lines. The slope of the lines as shewn indicate that BDI muskeg would increase about 7.5 psf and DFI muskeg about 8.5 psf per degree increase in angular deformation.

From a study of the Field Data Sheets and Computation Sheets it is seen that there is a definite difference in shear strengths for each state in which the muskeg was studied. For DFI Muskeg, as shewn on Computation Sheet No. 1, in the virgin state the average shear strength varies from 270 to 450 pounds per square foot. In the drained state the values varied from 300 to 650 psf and in the consolidated and drained state the shear strength varied from 625 to 850 psf. This indicates that DFI muskeg, under a consolidation load of approximately 400 psf for twenty-one months doubled in strength compared to the virgin state. The drained state shows a marked increase in strength compared to the virgin state.

The strengths recorded for the various states of BDI muskeg are from 150 to 500 psf for

the virgin state, from 325 to 650 for the drained state and from 400 to 700 psf for the consolidated state. Comparing the low values of shear strength obtained for each state shows that BDI muskeg drained gave twice the strength of virgin muskeg and that BDI consolidated shows nearly three times the strength of virgin muskeg. This type of muskeg was consolidated under a load of approximately 320 psf for ten months.

"C" class muskeg in the virgin state gave shear strengths from 550 to 765 psf. No consolidation or drainage had taken place in this tract of muskeg. The high strength in this vrigin state is likely due partially to the root growth extending throughout the total depth of the muskeg which was just two and three quarter feet. Fine hair roots were encountered five feet below the bottom of the muskeg in a grey-blue sandy clay.

CONCLUSIONS

The vane shear test apparatus, designed for and used in the collection of data for this study, met the design requirements.

The maximum shear strengths for the types of muskeg tested varied over a wide range, from 115 to 850 psf, but indicate that the shear strength in muskeg is increased by drainage and when under consolidation. The shear strengths of

muskeg were found to vary directly with the depth, inversely with moisture content and appeared to vary directly with angular deformation and ash content.

The shear strengths of muskegs determined in this study are in agreement with those determined by Capt. S. Thomson, as presented in his Thesis on the same subject and with the values obtained by C. F. Ripley and Associates from investigations carried out in the Campbell River area on Vancouver Island. The following tables show the comparison of the values obtained from the three different sources.

COMPARISON BETWEEN RESULTS OF THOMSON AND WYLD

(tests done in virgin muskeg)

	THOMSON				WYLD					
Depth to bottom of muskeg (ft)	12	12	13	17½	10½	10½	9½	10	6½	2 3/4
Depth of Max. Shear Str.(ft)	10½	12	4	17½	10	8	9	9½	6½	2
Max. Shear Strength (#/sft)	520	610	425	1090	480	600	525	600	500	765
Radforth Classification	unknown				DEI	DFI	BDI	BDI	ADI	C
Area Investigated	Alaska Highway				Pembina Oil Fields					

COMPARISON OF RESULTS OF RIPLEY & ASSOCIATES AND WYLD

	RIPLEY	WYLD
Undisturbed Strength (#/sq.ft)	150 to 300	175 to 600
Samples from Depth (ft)	0 to 7	1 to 10
Remolded Strength (#/sq/ft)	60 to 75	48 to 100
Water Content (%)	475 to 960	432 to 850
Under Consolidation		
a. Load	0.1 T/sq.ft	0.15 to 0.2 T/sq.ft
b. Increase in strength	25% to 100%	100% to 150%

RECOMMENDATIONS

It is felt that the following recommendations may be of some help in further investigations into

the engineering properties of muskeg.

A vane tester of similar design but of smaller dimensions and made of light weight materials will greatly reduce the work required in the field and will make the tester more portable. The Acker Vane Shear Test Kit, mentioned previously is suggested as a standard kit for such further investigations.

A suggested alteration to the Vane tester used by the author, to enable the application of torque at any desired rate is as follows. Axially fix the Torque wrench on to a cogged wheel of radius equal to the length of the Torque wrench and motivate the assembly by means of a hand operated worm screw.

Continued investigation is required to broaden and substantiate any conclusions indicated by this report. Such investigations should be conducted over divers and well dispersed muskeg areas. All data should be centrally collected thus allowing the best interpretation, and corelation of properties and classification.

FIELD DATA SHEET NO. 1.

VANE: height..4.1"..
diameter..6.0"

S = ..6. x T

Radforth Classification DEI
DFI

Weather Warm a.m.
Cloudy, rain p.m.

Date .2. / .8. / 56
31 7

Mobil Oil.. Block .1. LSD .6. Sec .15 Tp .48 Rg .8. W5

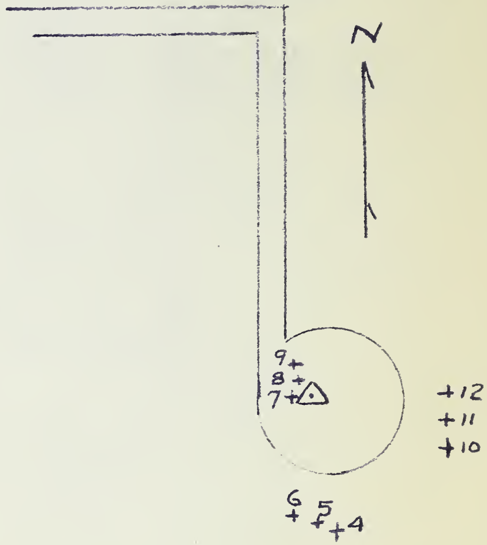
Wyld
MacFarlane
Kjorlien

Depth	T	Strain	rmld T	S
Hole # 1		(DEI)	*	
1	45	70	8	270
2	55	50	12	330
4	63	60	15	378
6	50	50	15	300
8	72	80	20	432
10	80	60	20	480
10'-6"	marl			
11	grey clay			
Hole # 2		(DEI)		
1	45	50	8	270
2	45	50	10	270
4	68	70	20	408
6	55	60	15	330
8	65	65	20	390
10	70	70		420
Hole # 3		(DEI)		
1	55	60	10	330
2	70	70	18	420
4	75	60	13	450
6	45	60	15	270
8	75	70	23	450
10	65	55	2	390
10'-3"	marl			

Depth	T	Strain	remld T	S
Hole # 4		(DFI)		
1	65	50	12	390
2	88	80	12	528
4	50	55	10	300
6	53	60	17	318
8	82	70	22	492
10	80	70	5	480
Hole # 5		(DFI)	*	
1	67	65	15	402
2	67	70	15	402
4	48	55	12	288
6	55	60	17	330
8	100	80	28	600
10	90	100	8	540
Hole # 6		(DFI)		
1	60	55	12	360
2	90	90	15	540
4	50	55	10	300
6	55	60	15	330
8	98	70	27	588
10	90	100	8	540

* means, Samples Taken

Depth	Sample No.
Hole # 1	
2	1
4	2
6	3
8	4
10	5
10½ to 11	6
Hole # 5	
2	7
4	8
6	9
8	10
9½ to 10	11



See Field Data Sheet No. .2. for completion of Field Sketch Detail

REMARKS
Hole # 2 - trace of marl at 10'
Hole # 4 - surface of marl at 10'
Hole # 5 - " " " " 10'
Hole # 6 - " " " " 10'

+ 1
+ 2
+ 3

Legal Sub-Divisions in a Section →

13	14	15	16
12	11	10	9
5	6	7	8
4	3	2	1

FIELD DATA SHEET NO. 8

VANE: height ...10.1"..
diameter...4.5...

S = ..5. x T

Radforth Classifiation DFI ......

Weather ..Hot......
....

Date .2. / .8. / 56

Mobil Oil.. Block .1.. LSD .6.. Sec .15. Tp .48. Rg .8.. W5

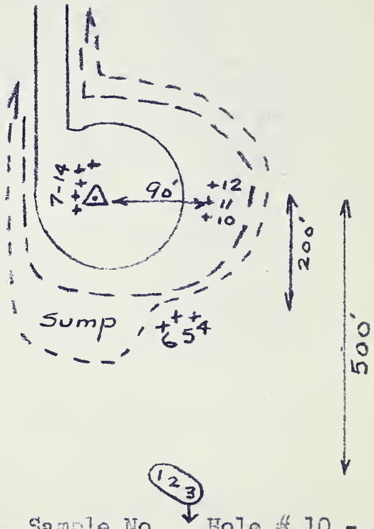
Depth	T	Strain	remld T	S
Hole # 7	(S = 6 x T)			
1	117	100	25	702
2	117	80	25	702
4	105	70	28	630
6	110	115	30	660
8	140	120	35	700
	started use of vane with S = 5 x T			
9	blue grey clay no marl present			
Hole # 8	(S = 5 x T)			
	4.5' of fill - island for holes # 7,8,9, 13 and 14			
2	160	180	40	800
4	170	100	30	850
6	125	120	35	625
8	155	125	50	775
9	clay as in hole # 7			
1	no rdg due to roots at surface of muskeg under 4.5' fill			
Hole # 9				
1	205	230	40	
	damaged vane - do not use values			

Depth	T	Strain	remld T	S
Hole # 10				
1	80	80	18	400
2	100	90	25	500
4	105	85	20	525
6	80	55	20	400
8	100	90	27	500
10	grey blue clay			
Hole # 11				
1	75	65	15	375
2	85	55	20	425
4	130	120	28	650
6	80	60	20	4 00
8	85	80	20	425
9	105	90	22	525
9'-6"	very organic silty blue clay			
Hole # 12				
1	75	70	15	375
2	85	65	20	425
4	95	85	20	475
6	75	65	20	375
8	60	65	10	300
9	95	75	20	475
9'-6"	clay as in hole # 11			

Drilling Island constructed in November 1954.
Contour levels run over an area of 1000' square with island at centre showed a fall of only 0.2' to the north.

Wyld
MacFarlane
Kjorlien
Erickson

See Data Sheet #.1..
for other details.



REMARKS

Hole # 7

Depth	Sample No.
1	12
2	13
4	14
6	15
8	16

Hole # 10 - trace of blue clay at 8'
Hole # 11 - probably encountere d log at 4'; 1" layer of blue clay at 8'

FIELD DATA SHEET NO. 3.

VANE: height ...10.1"....
diameter...4.5"....

S = .5. x T

Radforth
Classification
.DFI.

Weather ...Hot......
...80.......

Date 22. / .8. / 56

.Mobil Oil.. Block ..1 LSD .6. Sec .15 Tp 48. Rg .8. W5

Wyld
MacFarlane
Erickson

Depth	T	Strain	re mld T	S	Depth	T	Strain	remld T	S
Hole # 13		4.5' clay fill							
* 1	145	100	32	1030					
2	encountered log								
2'-6"	155	140	35	775					
4	160	115	35	800					
6	100	80	28	500					
* 8	145	130	45	805					
* - see remarks									
Hole 14		4.5' clay fill							
1	encountered roots								
1'-6"	160	115	35	800					
2'-6"	170	140	38	850					
4	160	115	35	800					
6	130	105	35	650					
* 8	135	130	40	750					
8'-9"	clay								
* - see remarks									

See Data Sheets Nos. .1. & .2. for Field Sketches.

REMARKS

Hole # 13 at 1' depth only 7" of vane in muskeg
at 8' " " 9" " " " "
Hole # 14 at 8' " " 9" " " " "
a ir escaped as fill was punctured at muskeg surface, samples in auger appeared lighter brown in color and somewhat drier than normally.

FIELD DATA SHEET NO. 4.

VANE: height....10.1"...
diameter...4.5"...

S = .5. x T

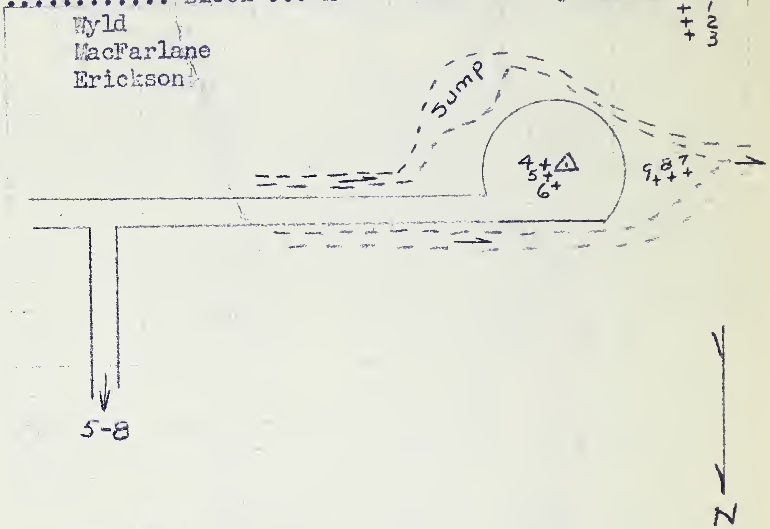
Radforth Classification B ..ADI.

Weather...hot......

Date .13 / .8. / 56

.Mobil Oil.. Block .3. LSD .2. Sec .5. Tp .49 Rg .8. W5

Wyld
MacFarlane
Erickson



Hole # 1

Depth	T	Strain	remld T	S
1	65	60	10	325
2	65	70	12	325
4	80	80	22	400
6	70	75	13	350
8	85	80	20	425
9	highly organic clay			

Hole # 2

Depth	T	Strain	remld T	S
1	40	70	8	200
2	37	55	10	185
4	68	60	20	340
6	70	75	15	350
8	75	90	22	375
9	105	90	20	525
9'-6"	highly organic clay			

Hole # 3

Depth	T	Strain	remld T	S
1	35	65	8	175
2	60	70	12	300
4	75	60	15	375
6	75	60	20	375
8	85	90	20	425
9	115	100	15	575
9'-3"	highly organic clay			

Hole # 4 3.5' fill-is land

Depth	T	Strain	remld T	S
1'	115	90	35	575
2'-6"	130	80	28	650
4'	120	100	30	600
6'	100	75	25	500
8'	highly organic clay			

Hole # 5 3.5' fill- island

Depth	T	Strain	remld T	S
1	112	80	25	560
2'-6"	175	120	28	875
4	110	100	28	550
6	100	80	23	500
8	highly organic clay			

water 8' below fill @ 1600 hrs
" 6" " " @ 0800 "

Hole # 6

Depth	T	Strain	remld T	S
1	12 5	120	25	780
2'-6"	135	75	35	675
4	120	100	25	600
6	115	85	28	575
8	highly organic clay			

Hole # 3

Depth	Sample No.
1	17
2	18
4	19
6	20
8	21
9	22
9'-3"	23

REMARKS

Hole #3	augered through rotten log at 7'-8'
Hole #4	first try abandoned- log at 1'-6"
Hole #6	depth 1' - used only 8" of vane
Hole #5	at 2'-6" rdg, felt root snap rdg will be high.

FIELD DATA SHEET NO. 5.

VANE: height....10.1"....
diameter....4.5"....

S = ..5.. x T

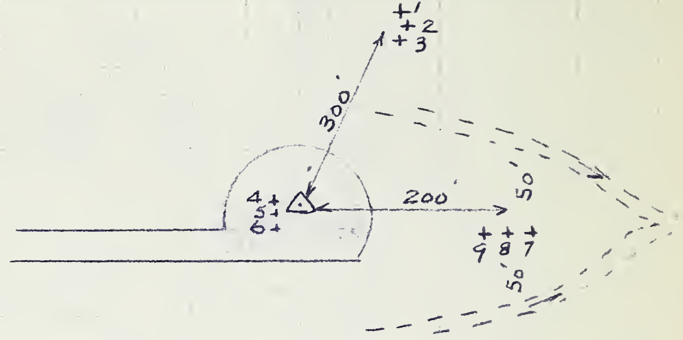
Radforth Classification .B ADI..

Weather ...Hot...

Date .15. / .8. / 56

.Mobil.Oil.. Block .3. LSD .2. Sec .5. Tp .49 Rg 8.. W5

Depth	T	Strian	remld T	S	De pth	T	Stra in	Remld T	S
Hole # 7									
1	65	65	15	325					
2	75	60	20	375					
4	155	120	25	775					
6	80	55	20	400					
8	105	90	27	525					
8'-3"	clay as in hole # 6								
Hole # 8									
1	85	65	17	425					
2	75	55	18	375					
4	110	90	18	550					
6	80	55	20	400					
8	110	100	20	550					
8'-4"	clay as in hole # 7								
Hole # 9									
1	82	75	18	410					
2	encountered log								
4	75	75	20	375					
6	85	60	20	425					
8	105	105	60	660					
8'-4"	clay as in hole # 8								



See Data Sheet # .4. for other Field Sketch Detail

REMARKS

Hole # 9 - 8 ' depth only 8" of vane used
Hole # 7 - wa tch for high rdg at 4'depth
possible root

FIELD DATA SHEET 6

VANE: height ..10.1"
diameter..4.5"

S = ..5. x T

Radforth
Classification
..BDI...

Weather ..Hot.....
..85......

Date .17 / .8. / 56

.Mobil.Oil.. Block .3. LSD .8. Sec .5. Tp 49. Rg .8. W5

Wyld
MacFarlane
Erickson

Hole # 1

Depth	T	Strain	remld T	S
1	30	50	10	150
2	55	55	12	275
4	65	70	15	325
6	65	60	18	325
8	100	100	20	500
9'-8"	120	100	20	600
10	2" light marl then grey clay			

Hole # 2

Depth	T	Strain	remld T	S
1	30	60	7	150
2	70	70	15	350
4	65	75	15	325
6	55	55	15	275
8	80	85	20	400
9'-6"	115	90	20	575
10	clay - no marl			

Hole #3 20.8.56

Depth	T	Strain	remld T	S
1	30	60	7	150
2	50	50	15	250
4	60	60	17	300
6	70	65	17	350
8	100	100	25	500
9'-6"	135	110	20	675
10	clay as in hole # 2			

Hole #4 3'-6" fill; island

Depth	T	Strain	remld T	S
6""	120	80	28	600
2'-6"	112	75	25	560
4'-6"	95	90	25	475
6'-6"	85	80	23	425
8	120	120	30	600
8'-8"	115	120	27	575
9'-3"	dark organic clay			

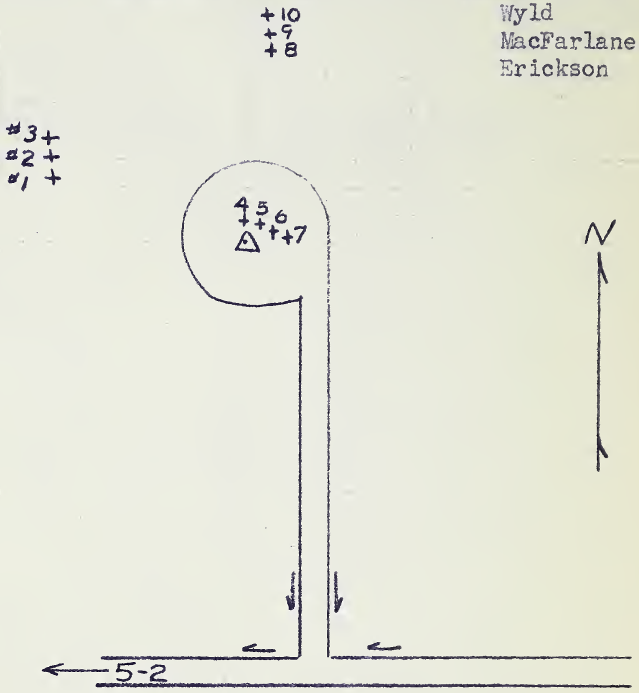
Hole # 5 3'-6" fill; island

Depth	T	Strain	remld T	S
1	125	100	25	625
2	135	80	28	675
4	75	70	20	375
6	85	75	22	425
8	110	115	30	550
9'-6"	clay-soft plastic trace of marl			

Hole # 6 3'-6" fill; island

encountered log at 3'-3" in fill

Depth	T	Strain	remld T	S
1	no rdg - roots			
2	120	80	15	
	-5" of vane			1450
	snap of root felt on vane			
3'-6"	log-abandoned hole			



△ well head + test hole ↑ drainage

REMARKS

Hole #4 - 1'-6" disturbed muskeg + 2' fill
Hole #6 - at 2' rdg minus 5" of vane

FIELD DATA SHEET NO. 7.

VANE: height ..10.1".. S = ..5. x T Radforth Classification ..BDI... Weather ..Hot..... Date .21 / .8. / 56

diameter..4.5"..

.Mobil.Oil.. Block .3. LSD .8. Sec .5. Tp 49. Rg .8. W5

Wyld
MacFarlane
Erickson

Depth	T	Strain	remld T	S
Hole # 7	3'-6" fill; island			
1	135	95	25	675
2	110	70	28	550
5	90	95	23	450
6	85	75	20	425
8	120	130	33	600
9'-6"	Clay as in Hole # 5			
Hole # 8				
1	28	60	5	140
2	55	70	12	275
# 4	130	95	15	650
6	70	75	13	350
8	80	85	22	400
9'-6"	93	80	28	465
10'-6"	Silty clay highly organic			
Hole # 9				
1	23	55	5	115
2	40	55	8	200
4	75	105	12	375
7	70	90	15	350
8	55	65	12	275
9'-6"	100	90	25	500
10'-6"	Clay as in hole # 8			

Depth	T	remld T	Strain	S
Hole # 10				
1	encountered root			
2	55	60	8	275
4	55	75	12	275
6	95	100	16	475
8	65	85	15	325
9'-9"	90	75	20	450
10'-3"	Clay as in hole # 9			

See Data Sheet # 6 for Field Sketch.

REMARKS

Hole # 7 - pushed vane past 4' rdg at 5'

Hole # 8 - at 4' watch for high rdg as vane appea red to contact root during rotation

FIELD DATA SHEET NO. 8.

VANE: height ...10.1 "....
diameter ..4.5 "....

S = .5. x T

Radforth
Classification
.A^B^DI

Weather rainy..am...
sunny..pm...

Date .24 / .8. / 56 .

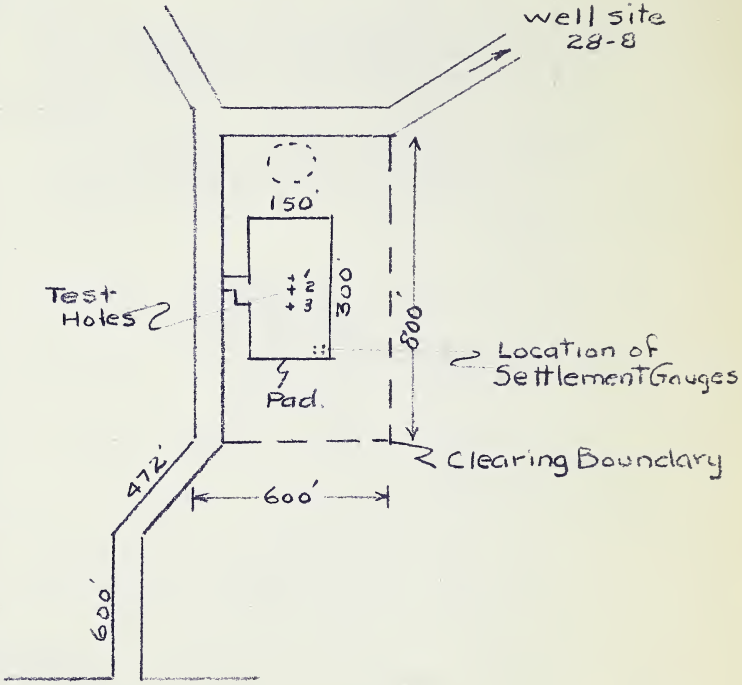
Mobil.Oil... Block .4. LSD ... Sec .28 Tp 49. Rg .8. W5
Site of Battery # N. P. 28

Depth	T	Strain	remld T	S
Hole # 1				
1	55	70	12	275
2	65	55	15	325
4	110	85	12	550
5'-9"	90	65	20	500
6'-3"	grey clay			
Hole # 2				
1	85	70	18	425
2	70	50	13	350
4	95	80	12	475
5'-6"	100	75	20	500
6'-3"	grey clay			
Hole # 3				
1	80	65	20	400
2	70	65	13	350
4	83	75	12	415
5'-6"	95	75	13	475
6'-3"	grey clay			

Depth	T	Stra in	remld T	S

Radforth Classifica tion

A - dense over 15'
B-D - dense 2'-15'
I - surface mat of moss with some grass



REMARKS

Test Holes in virgin muskeg as shewn, pad to be constructed approx 3'-6" thick. Hole # 1 - at 5'-9" used only 9" of vane Four settlement gauges installed as indicated.

F I E L D   D A T A   S H E E T   N O. 9.

VANE : height ....10.1"...
diameter ...4.5"...

S = .5. x T

Radforth Classification "C"

Weather ...Cloudy...
...Cool.....

Date 30. / .8. / 56

Trans.Canada Block ... LSD 15. Sec .19 Tp .47 Rg .7. W5

Hole # 1

Depth	T	Strain	remld T	S
1	110	90	12	550
2	130	65	12	765

2'-9" clay - heavy organic dark grey well mixed with roots

5'-3" clay - soft blue grey silty with very fine sand, a few grains of white sand visible

7'-6" clay - high sand content, with the appearance of " SNAP " cleanser fine hair like roots apparent

9'-3" clay - blue grey, silt andsand both noticeably less than at 7'-6" no hair roots visible

10'-3" clay - blue grey with high fine sand content and trace of silt

11'-6" clay - blue grey with trace of fine grained sand.

Hole # 2

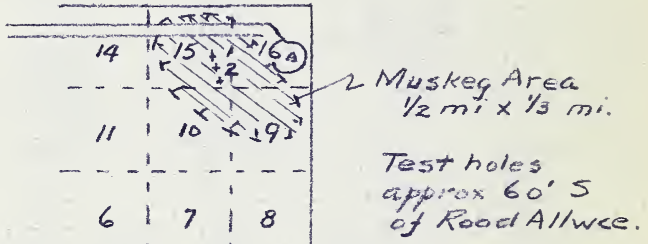
Depth	T	Strain	remld T	S
1	110	80	12	550
2	130	70	10	765

2'-9" clay as in hole # 1

Note:

This area pointed out by Mobil Oil and Road Construction personnel as a very difficult area, suggestion that the muskeg was very deep.

The area was solely Class "C" by Radforth Classification - grass 3'-6" high with no presence of moss or woody growth.



Surface Mat very tough

REMARKS

Hole # 1 at 2' - used 8½" of vane
Hole # 2 at 2' - " 8½" of "
Water table approx 2" above ground level

MOISTURE AND ASH CONTENTS - DATA SHEET NO 10.

Sample No.	Cont. No.	Wt. Sample Wet + Tare	Wt. Sample Dry + Tare	Weight of Water	Tare Container	Wt. of Dry Soil	w %	Wt. Ash + Tare	Weight of Ash	Ash Content %
1	A1	108.97	68.73	40.24	63.64	5.09	791	64.13	0.49	9.6
2	A2	102.29	68.43	33.86	62.91	5.52	613	63.52	0.61	11.0
3	A3	105.00	72.48	32.52	67.93	4.55	715	68.33	0.40	8.8
4	A21	115.47	81.50	33.97	75.57	5.93	573	76.56	0.99	16.7
5	A22	106.47	76.10	30.37	69.75	6.35	478	73.38	3.63	57.2
6	A23	130.02	99.66	30.36	71.67	27.99	109	98.81	27.14	96.9
7	A24	127.71	79.53	48.18	72.43	7.10	679	73.13	0.70	9.3
8	V11	119.40	82.28	37.12	76.88	5.40	687	77.45	0.57	10.6
9	V13	123.57	76.57	47.00	71.03	5.54	850	71.46	0.43	7.8
10	V16	102.66	66.48	36.18	60.62	5.86	617	61.40	0.78	13.3
11	V23	110.68	74.40	36.28	65.99	8.41	432	69.13	3.14	37.3
12	V28	103.65	72.96	30.69	65.61	7.35	418	67.72	2.11	28.7
13	V40	123.84	79.80	44.04	70.95	8.85	498	73.11	2.16	24.4
14	V41	101.20	70.49	30.71	64.78	5.71	538	65.67	0.89	15.6
15	V42	117.48	74.12	43.36	65.55	8.57	505	67.49	1.94	22.7
16	V45	104.80	76.16	28.64	69.70	6.46	443	70.82	1.12	17.3
17	V47	107.28	67.08	40.20	64.02	3.06	1315	64.37	0.35	11.4
18	V48	113.64	78.06	35.58	74.10	3.96	900	74.68	0.58	14.6
19	V49	128.00	78.67	49.33	71.56	7.11	694	72.23	0.67	9.4
20	V50	147.53	94.98	52.55	87.64	7.34	717	88.50	0.86	11.7
21	V51	122.40	73.75	58.65	67.18	6.57	895	67.80	0.62	9.4
22	V52	128.00	77.30	50.70	70.71	6.59	770	71.41	0.70	10.6
23	V53	128.54	84.82	43.72	61.61	23.21	188	80.72	19.11	82.4

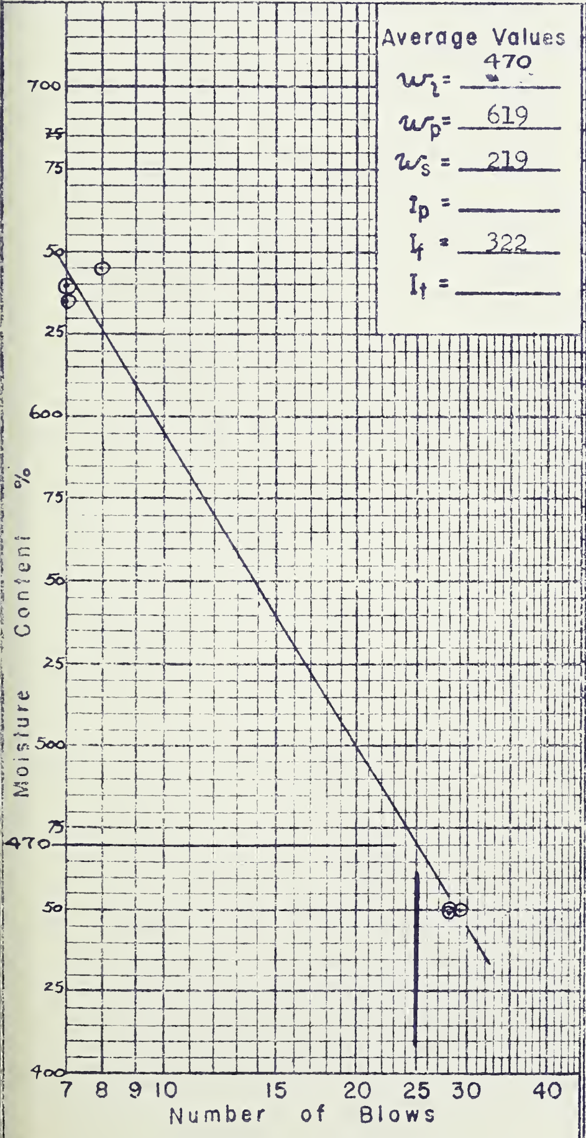
UNIVERSITY of ALBERTA
DEP'T of CIVIL ENGINEERING
SOIL MECHANICS LABORATORY

ATTERBERG LIMITS

PROJECT MUSKEG RESEARCH
SITE Pembina Oil Fields
SAMPLE # 2
LOCATION
HOLE #1 DEPTH 4'
TECHNICIAN RW DATE Oct 56

Liquid Limit

Trial No.	1	2	3	4	5	6
No. of Blows	7	8	7	28	29	28
Container No.	V49	V50	V51	A21	A22	A23
Wt. Sample Wet + Tare	83.6949	101.7980	82.0661	90.2250	81.1243	91.4276
Wt. Sample Dry + Tare	73.2304	89.5545	69.2220	78.2422	71.8130	75.2618
Wt. Water	10.4645	12.2435	12.8441	11.9828	9.3113	16.1658
Tare Container	71.5841	87.6574	67.1820	75.5734	69.7503	71.6690
Wt. of Dry Soil	1.6463	1.7981	2.0400	2.6688	2.0627	3.5928
Moisture Content w%	635	645	640	449	450	450



Average Values
w_l = 470
w_p = 619
w_s = 219
I_p =
I_f = 322
I_t =

Plastic Limit

Trial No.	1	2	3
Container No.	AV	BI	AJ
Wt. Sample Wet + Tare	57.1623	57.3863	56.9883
Wt. Sample Dry + Tare	54.8189	55.3193	54.3075
Wt. Water	2.3434	2.0670	2.6808
Tare Container	54.4458	54.9808	53.9948
Wt. of Dry Soil	0.3731	0.3385	0.3127
Moisture Content %	628	611	~~850?~~

Shrinkage Limit

$w_p = 619$

Trial No.	1	2	3
Container No.	15	16	17
Wt. Sample Wet + Tare	132.471	130.930	123.347
Wt. Sample Dry + Tare	121.175	119.364	112.074
Wt. Water	11.297	11.566	11.273
Tare Container	119.660	117.812	110.550
Wt. of Dry Soil W_o	1.515	1.551	0.313
Moisture Content w%	746	745	740
Vol. Container V	12.10	12.35	12.00
Vol. Dry Soil Pat V_o	4.15	4.30	3.90
Shrinkage Vol. $V-V_o$	7.95	8.05	8.10
Shrinkage Limit w_s	221	227	209

$$w_s = w\left(\frac{V-V_o}{W_o} \times 100\right)$$

$w_s = 219$

Description of Sample:

Remarks:

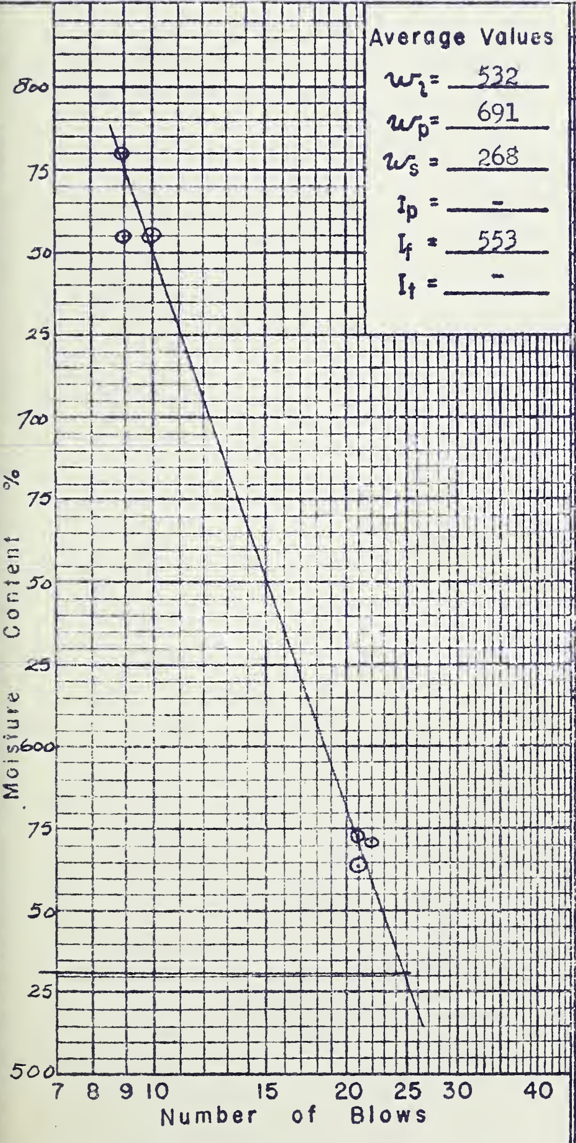
DATA SHEET NO. 12

UNIVERSITY of ALBERTA
DEP'T of CIVIL ENGINEERING
SOIL MECHANICS LABORATORY
ATTERBERG LIMITS

PROJECT Muskeg Research
SITE Pembina Oil Fields
SAMPLE #3
LOCATION
HOLE #1 DEPTH 6'
TECHNICIAN RW DATE Oct 56

Liquid Limit

Trial No.	1	2	3	4	5	6
No. of Blows	9	9	10	21	22	21
Container No.	V40	V41	V42	V52	V53	A1
Wt. Sample Wet + Tare	89.3537	77.1006	80.5785	82.8280	77.3092	78.2966
Wt. Sample Dry + Tare	73.1061	66.1797	67.3084	72.5590	63.9635	65.8112
Wt. Water	16.2476	10.9209	13.2701	10.2690	13.3457	12.4854
Tare Container	70.9537	64.7806	65.5498	70.7273	61.6410	63.6375
Wt. of Dry Soil	2.1524	1.3991	1.7586	1.8217	2.3235	2.1737
Moisture Content w%	755	780	755	564	571	573



Average Values
w_l = 532
w_p = 691
w_s = 268
I_p = -
I_f = 553
I_t = -

Plastic Limit

Trial No.	1	2	3
Container No.	W1	W2	W3
Wt. Sample Wet + Tare	41.045	38.567	39.060
Wt. Sample Dry + Tare	39.343	36.425	37.052
Wt. Water	1.702	2.141	2.008
Tare Container	39.098	36.120	36.756
Wt. of Dry Soil	0.245	0.305	0.296
Moisture Content %	694	703	677

Shrinkage Limit

Trial No.	1	2	3
Container No.	19	23	25
Wt. Sample Wet + Tare	128.029	141.032	136.996
Wt. Sample Dry + Tare	116.555	129.576	125.146
Wt. Water	11.474	11.455	11.851
Tare Container	115.477	128.622	124.031
Wt. of Dry Soil W_o	1.078	0.954	1.115
Moisture Content w%	1065	1200	1065
Vol. Container V	12.70	12.25	12.75
Vol. Dry Soil Pat V_o	3.65	3.55	3.95
Shrinkage Vol. $V-V_o$	9.05	8.70	8.60
Shrinkage Limit w_s	224	288	294

$$w_s = w - \left(\frac{V-V_o}{W_o} \times 100\right)$$

Description of Sample:

Remarks:

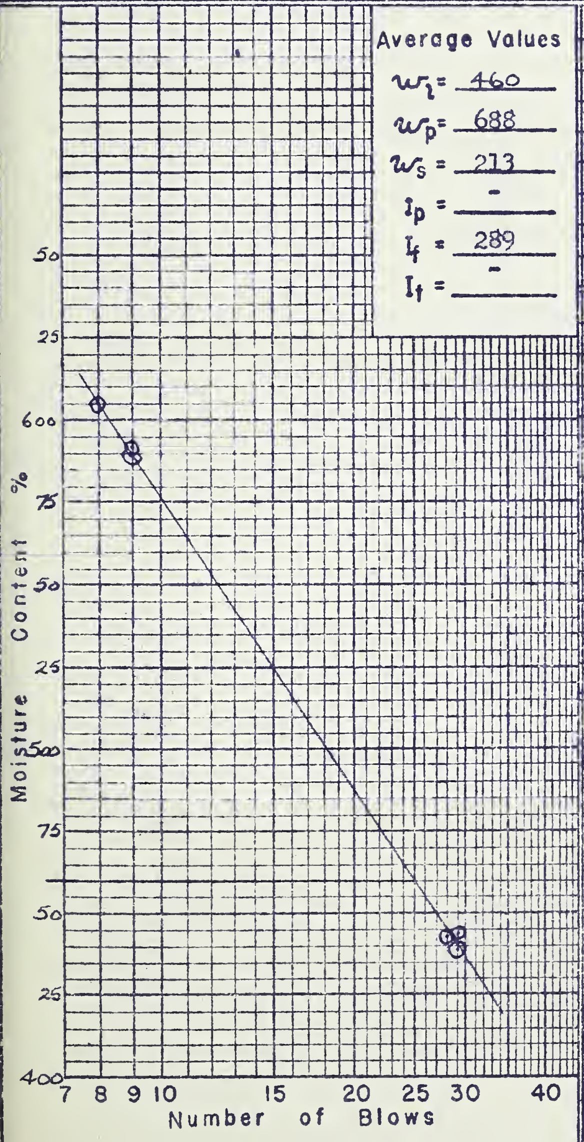
DATA SHEET NO. 13

UNIVERSITY of ALBERTA
DEP'T· of CIVIL ENGINEERING
SOIL MECHANICS LABORATORY
ATTERBERG LIMITS

PROJECT	Muskeg Research		
SITE	Pembina Oil Fields		
SAMPLE	#4		
LOCATION			
HOLE	#1	DEPTH	8'
TECHNICIAN	RW	DATE	Oct 56

Liquid Limit

Trial No·	1	2	3	4	5	6
No· of Blows	9	8	9	28	29	29
Container No·	V16	V23	V28	V45	V47	V48
Wt· Sample Wet + Tare	71.5682	77.2462	79.8327	81.6400	77.4276	88.1462
Wt· Sample Dry + Tare	62.2023	67.5860	68.8933	71.8983	66.4293	76.7023
Wt· Water	9.3659	9.6602	10.9394	9.7417	10.9483	11.4439
Tare Container	60.6227	65.9928	67.0405	69.7035	64.0160	74.0950
Wt· of Dry Soil	1.5796	1.5932	1.8528	2.1948	2.4633	2.6073
Moisture Content w%	592	605	590	443	444	439



Average Values

w_l = 460

w_p = 688

w_s = 213

I_p = -

I_l = 289

I_f = -

Plastic Limit

Trial No·	1	2	3
Container No·	W4	W5	W6
Wt· Sample Wet+Tare	37.859	38.365	40.254
Wt· Sample Dry + Tare	35.656	36.130	37.970
Wt· Water	2.203	2.235	2.286
Tare Container	35.338	35.811	37.631
Wt· of Dry Soil	0.318	0.319	0.339
Moisture Content %	692	692	680

Shrinkage Limit

Trial No·	1	2	3
Container No·	8	9	10
Wt· Sample Wet + Tare	134.046	129.664	124.648
Wt· Sample Dry + Tare	122.573	118.390	113.210
Wt· Water	11.473	11.275	11.438
Tare Container	121.033	116.890	111.689
Wt· of Dry Soil W_o	1.540	1.500	1.521
Moisture Content w%	745	750	750
Vol· Container V	12.35	12.25	12.90
Vol· Dry Soil Pat V_o	4.30	4.70	4.10
Shrinkage Vol· $V-V_o$	8.05	7.55	8.80
Shrinkage Limit w_s	222	247	172

$$w_s = w \left(\frac{V-V_o}{W_o} \times 100\right)$$

Description of Sample: ________

Remarks: ________

DATA SHEET NO. 14

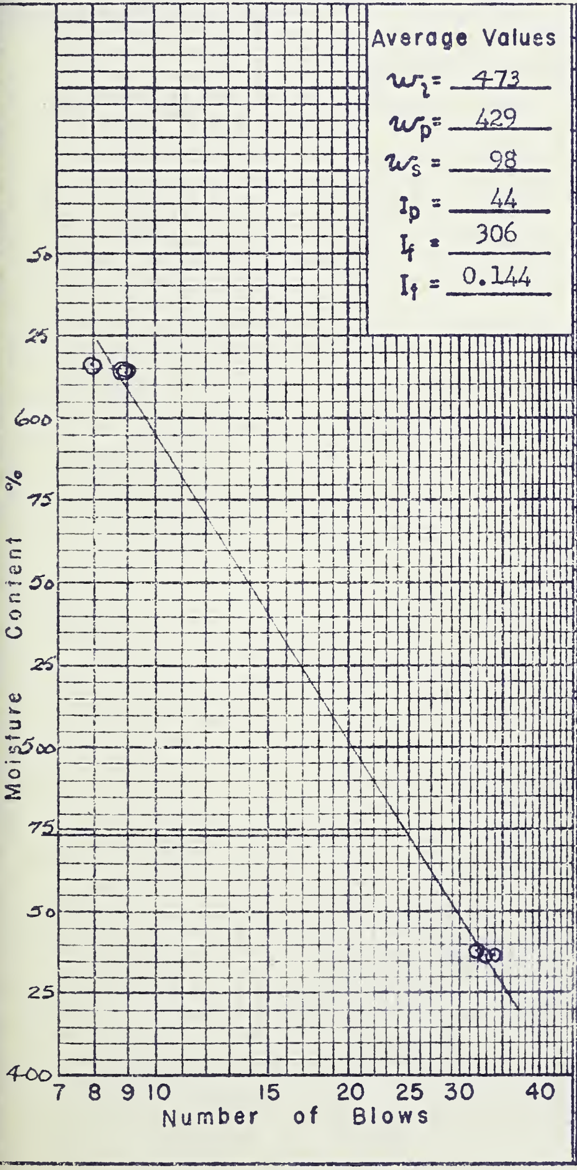
UNIVERSITY of ALBERTA
DEP'T. of CIVIL ENGINEERING
SOIL MECHANICS LABORATORY

ATTERBERG LIMITS

PROJECT Muskeg Research
SITE Pembina Oil Fields
SAMPLE #5
LOCATION
HOLE #1 DEPTH 10'
TECHNICIAN RW DATE Oct 56

Liquid Limit

Trial No.	1	2	3	4	5	6
No. of Blows	9	8	9	32	33	34
Container No.	A1	A2	A3	A21	A22	A23
Wt. Sample Wet + Tare	74.6605	75.2400	80.0045	90.4646	82.6371	82.3553
Wt. Sample Dry + Tare	65.1817	64.6355	69.6190	78.3379	72.1508	73.6586
Wt. Water	9.4788	10.6045	10.3853	12.1267	10.4863	8.6967
Tare Container	63.6375	62.9115	67.9254	75.5734	69.7503	71.6690
Wt. of Dry Soil	1.5442	1.7240	1.6936	2.7645	2.4005	1.9896
Moisture Content w%	614	616	614	438	437	437



Average Values

w_l = 473
w_p = 429
w_s = 98
I_p = 44
I_f = 306
I_t = 0.144

Plastic Limit

Trial No.	1	2	3
Container No.	W1	W2	W3
Wt. Sample Wet+Tare	41.391	38.162	38.734
Wt. Sample Dry+Tare	39.532	36.506	37.129
Wt. Water	1.859	1.656	1.605
Tare Container	39.098	36.120	36.756
Wt. of Dry Soil	0.434	0.386	0.373
Moisture Content %	429	429	430

Shrinkage Limit

Trial No.	1	2	3
Container No.	8	9	10
Wt. Sample Wet + Tare	133.741	129.247	124.414
Wt. Sample Dry + Tare	122.947	118.627	113.508
Wt. Water	10.795	10.620	10.906
Tare Container	121.033	116.890	111.689
Wt. of Dry Soil W_o	1.914	1.737	1.319
Moisture Content w%	563	611	600
Vol. Container V	12.35	12.25	12.90
Vol. Dry Soil Pat V_o	3.65	3.35	3.55
Shrinkage Vol. $V-V_o$	8.70	8.90	9.35
Shrinkage Limit w_s	108	100	87

$$w_s = w \left(\frac{V-V_o}{W_o} \times 100\right)$$

Description of Sample:

Remarks:

DATA SHEET NO. 15

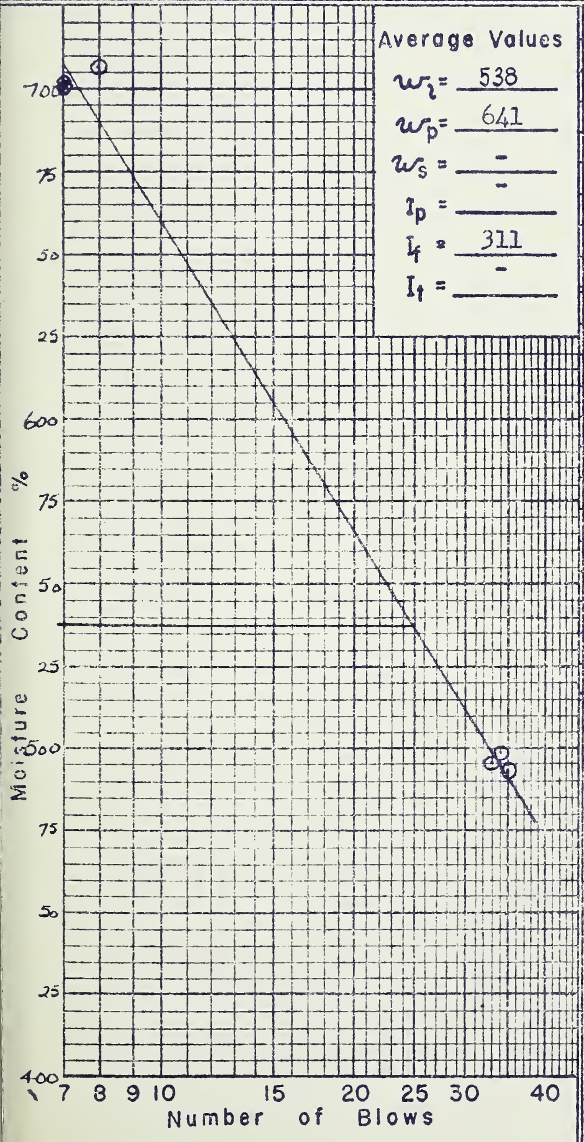
UNIVERSITY of ALBERTA
DEP'T of CIVIL ENGINEERING
SOIL MECHANICS LABORATORY

ATTERBERG LIMITS

PROJECT	Muskeg Research		
SITE	Pembina Oil Fields		
SAMPLE	#8		
LOCATION			
HOLE	#5	DEPTH	4'
TECHNICIAN	BW	DATE	Oct 56

Liquid Limit

Trial No.	1	2	3	4	5	6
No. of Blows	7	7	8	33	35	34
Container No.	A2	A3	V28	A1	A21	A22
Wt. Sample Wet + Tare	79.5448	85.6793	84.3957	79.7466	89.5723	83.9398
Wt. Sample Dry + Tare	64.9910	70.1503	69.1940	66.3430	77.9387	72.1180
Wt. Water	14.5538	15.5290	15.2017	13.4036	11.6336	11.8218
Tare Container	62.9115	67.9254	67.0405	63.6375	75.5734	69.7503
Wt. of Dry Soil	2.0795	2.2249	2.1535	2.7055	2.3653	2.3677
Moisture Content w%	700	701	707	495	493	499



Average Values

w_l = 538

w_p = 641

w_s = -

I_p = -

I_f = 311

I_t = -

Plastic Limit

Trial No.	1	2	3
Container No.	AV	BK	AD
Wt. Sample Wet + Tare	55.649	54.394	54.502
Wt. Sample Dry + Tare	54.609	53.420	52.621
Wt. Water	1.040	0.974	1.881
Tare Container	54.446	53.267	52.331
Wt. of Dry Soil	0.163	0.153	0.290
Moisture Content %	638	636	648

Shrinkage Limit

Trial No.			
Container No.			
Wt. Sample Wet + Tare			
Wt. Sample Dry + Tare			
Wt. Water			
Tare Container			
Wt. of Dry Soil W_o			
Moisture Content w%			
Vol. Container V			
Vol. Dry Soil Pat V_o			
Shrinkage Vol. $V-V_o$			
Shrinkage Limit w_s			

$$w_s = w - \left(\frac{V-V_o}{W_o} \times 100\right)$$

Description of Sample: ______

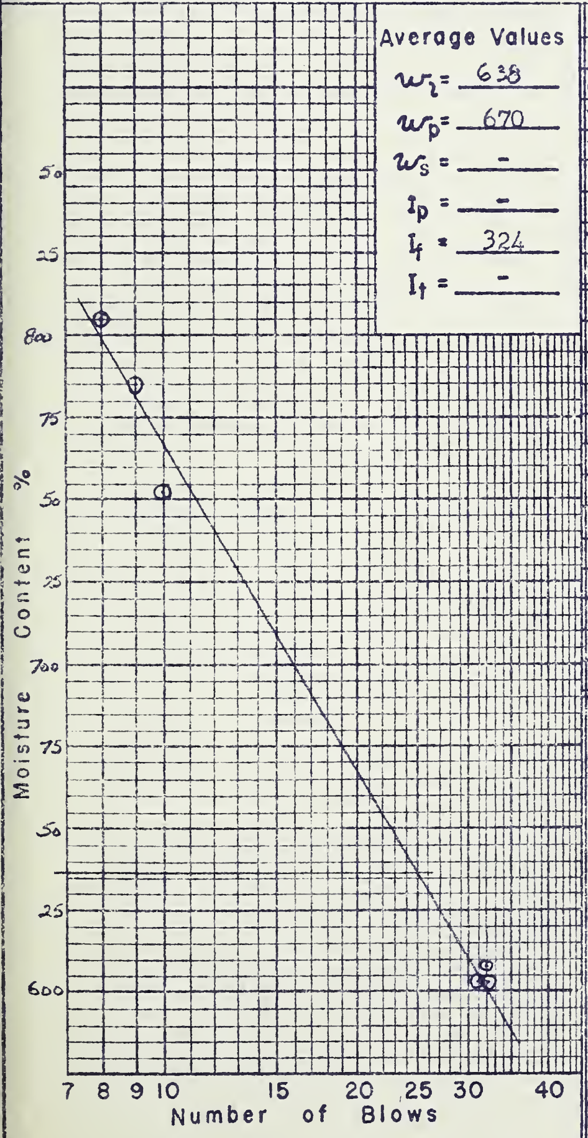
Remarks: ______

UNIVERSITY of ALBERTA
DEP'T· of CIVIL ENGINEERING
SOIL MECHANICS LABORATORY
ATTERBERG LIMITS

PROJECT	Muskeg Research		
SITE	Pembina Oil Fields		
SAMPLE	# 9		
LOCATION			
HOLE	# 5	DEPTH	6'
TECHNICIAN:	RW	DATE	Oct 56

Liquid Limit

Trial No.	1	2	3	4	5	6
No. of Blows	10	9	8	32	31	32
Container No.	V42	V49	V50	V40	V41	V45
Wt· Sample Wet + Tare	80.7254	87.0705	104.3886	83.0025	80.6164	86.1328
Wt· Sample Dry + Tare	67.3290	73.3330	89.5015	72.6546	67.0334	72.0320
Wt· Water	13.3964	13.7375	14.8871	10.3479	13.5830	14.1008
Tare Container	65.5498	71.5841	87.6574	70.9537	64.7806	69.7035
Wt· of Dry Soil	1.7792	1.7489	1.8441	1.7009	2.2528	2.3285
Moisture Content w%	752	785	805	608	603	603



Average Values

w_l = 638

w_p = 670

w_s = -

I_p = -

I_f = 324

I_t = -

Plastic Limit

Trial No.	1	2	3
Container No.	BW	AJ	BI
Wt· Sample Wet+Tare	56.281	55.346	56.357
Wt· Sample Dry+Tare	54.938	54.173	55.158
Wt· Water	1.343	1.173	1.199
Tare Container	54.738	53.996	54.981
Wt· of Dry Soil	0.200	0.177	0.177
Moisture Content %	671	663	676

Shrinkage Limit

Trial No.			
Container No.			
Wt· Sample Wet + Tare			
Wt· Sample Dry + Tare			
Wt· Water			
Tare Container			
Wt· of Dry Soil W_o			
Moisture Content w%			
Vol· Container V			
Vol· Dry Soil Pat V_o			
Shrinkage Vol· $V-V_o$			
Shrinkage Limit w_s			

$$w_s = w - \left(\frac{V-V_o}{W_o} \times 100\right)$$

Description of Sample: ______

Remarks: ______

DATA SHEET NO. 17

44.

UNIVERSITY of ALBERTA
DEP'T of CIVIL ENGINEERING
SOIL MECHANICS LABORATORY

ATTERBERG LIMITS

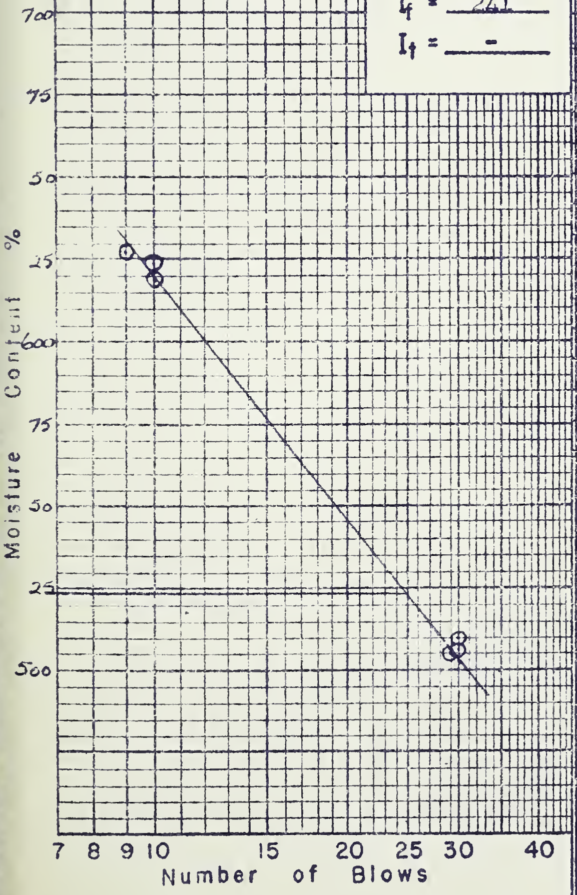
PROJECT Muskeg Research
SITE Pembina Oil Fields
SAMPLE # 10
LOCATION
HOLE #5 DEPTH 8'
TECHNICIAN BW DATE Oct 56

Liquid Limit

Trial No.	1	2	3	4	5	6
No. of Blows	10	10	9	30	30	29
Container No.	V51	V52	V53	V47	V48	A24
Wt. Sample Wet + Tare	82.3613	87.0347	79.7950	76.1806	87.0453	86.0236
Wt. Sample Dry + Tare	69.2925	72.9738	64.1382	66.0113	76.2300	74.6794
Wt. Water	13.0688	14.0609	15.6568	10.1693	10.8153	11.3442
Tare Container	6711820	70.7273	61.6410	64.0160	74.0950	72.4316
Wt. of Dry Soil	2.1105	2.2465	2.4972	1.9953	2.1350	2.2478
Moisture Content w%	619	624	626	510	507	505

Average Values

w_l = 524
w_p = 561
w_s = -
I_p = -
I_f = 241
I_t = -



Plastic Limit

Trial No.	1	2	3
Container No.	1	2	3
Wt. Sample Wet + Tare	37.624	38.418	38.826
Wt. Sample Dry + Tare	35.972	36.677	36.793
Wt. Water	1.652	1.741	2.033
Tare Container	35.682	36.367	36.425
Wt. of Dry Soil	0.290	0.310	0.368
Moisture Content %	570	562	553

Shrinkage Limit

Trial No.			
Container No.			
Wt. Sample Wet + Tare			
Wt. Sample Dry + Tare			
Wt. Water			
Tare Container			
Wt. of Dry Soil W_o			
Moisture Content w%			
Vol. Container V			
Vol. Dry Soil Pat V_o			
Shrinkage Vol. $V-V_o$			
Shrinkage Limit w_s			

$$w_s = w\left(\frac{V-V_o}{W_o} \times 100\right)$$

Description of Sample:

Remarks:

DATA SHEET NO. 18

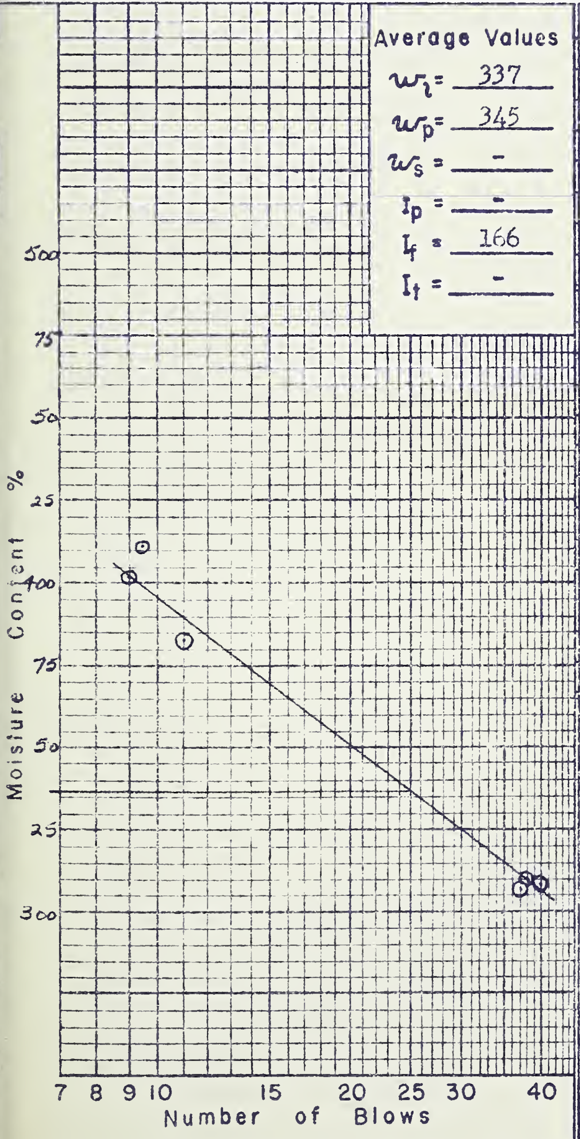
UNIVERSITY of ALBERTA
DEP'T. of CIVIL ENGINEERING
SOIL MECHANICS LABORATORY

ATTERBERG LIMITS

PROJECT	Muskeg Research		
SITE	Pembina Oil Fields		
SAMPLE	# 11		
LOCATION			
HOLE	#5	DEPTH	9'-6"
TECHNICIAN	RW	DATE	Oct 56

Liquid Limit

Trial No.	1	2	3	4	5	6
No. of Blows	9	11	9½	37	38	40
Container No.	V13	V16	V23	A23	A24	V11
Wt. Sample Wet + Tare	84.5195	74.5690	81.8060	83.8463	82.7528	88.7239
Wt. Sample Dry + Tare	73.7168	63.5094	69.0758	75.2318	74.3767	79.7759
Wt. Water	10.8027	11.0596	12.7302	8.6145	8.3761	8.9480
Tare Container	71.0344	60.6227	65.9928	72.4316	71.6690	76.[illegible]816
Wt. of Dry Soil	2.6824	2.8867	3.0830	2.8002	2.7077	2.8943
Moisture Content $w\%$	402	383	412	307	310	309



Average Values

w_l = 337
w_p = 345
w_s = -
I_p = -
I_f = 166
I_t = -

Plastic Limit

Trial No.	1	2	3
Container No.	4	5	6
Wt. Sample Wet+Tare	39.405	40.395	39.142
Wt. Sample Dry+Tare	37.698	38.533	37.441
Wt. Water	1.707	1.862	1.701
Tare Container	37.214	37.999	36.935
Wt. of Dry Soil	0.484	0.534	0.506
Moisture Content %	353	349	336

Shrinkage Limit

Trial No.			
Container No.			
Wt. Sample Wet + Tare			
Wt. Sample Dry + Tare			
Wt. Water			
Tare Container			
Wt. of Dry Soil W_o			
Moisture Content $w\%$			
Vol. Container V			
Vol. Dry Soil Pat V_o			
Shrinkage Vol. $V-V_o$			
Shrinkage Limit w_s			

$$w_s = w - \left(\frac{V-V_o}{W_o} \times 100\right)$$

Description of Sample: ____________________

Remarks: ____________________

DATA SHEET NO. 19

UNIVERSITY of ALBERTA
DEP'T. of CIVIL ENGINEERING
SOIL MECHANICS LABORATORY
ATTERBERG LIMITS

PROJECT Muskeg Research
SITE Pembina Oil Fields
SAMPLE # 23
LOCATION
HOLE #7 DEPTH 9'-3"
TECHNICIAN RW DATE Oct 56

Liquid Limit

Trial No.	1	2	3	4	5	6
No. of Blows	7	8	7½	24	25	23
Container No.	V49	V52	V45	A1	V13	V28
Wt. Sample Wet + Tare	87.1683	83.3134	84.8627	80.6365	85.5609	82.6576
Wt. Sample Dry + Tare	76.4324	74.9183	74.6190	70.4730	76.9571	73.2026
Wt. Water	10.7359	8.3951	10.2437	10.1635	8.6038	9.4550
Tare Container	71.5841	70.7273	69.7035	63.6375	71.0344	67.0405
Wt. of Dry Soil	4.8483	4.1910	4.9155	6.8355	5.9227	6.1621
Moisture Content w%	222	200	209	149	145	153

Average Values

w_l = 147

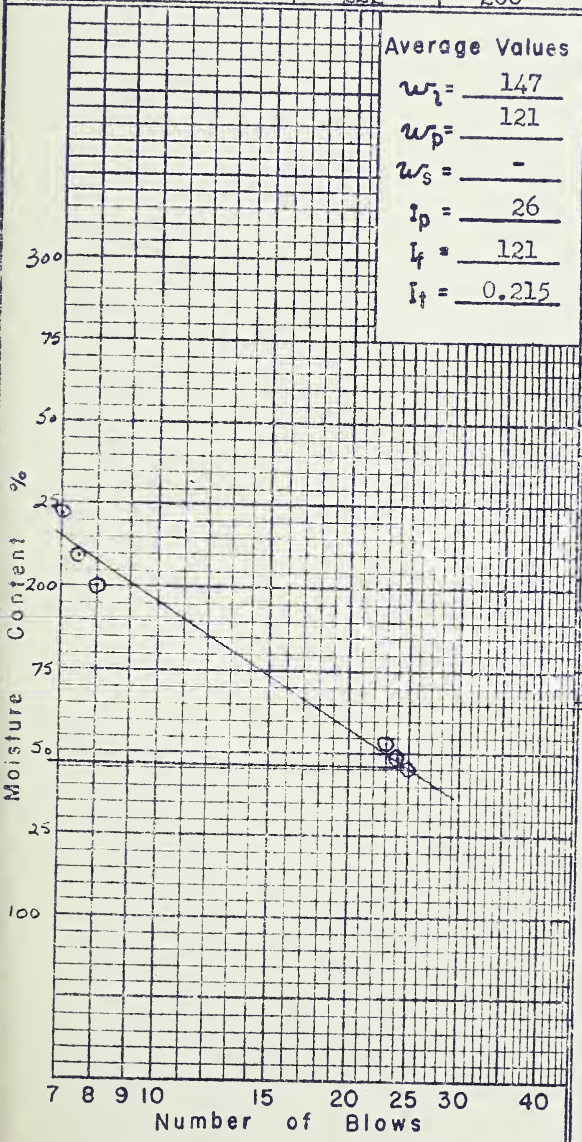
w_p = 121

w_s = -

I_p = 26

I_f = 121

I_t = 0.215



Plastic Limit

Trial No.	1	2	3
Container No.	BK	AD	AV
Wt. Sample Wet + Tare	56.080	55.547	56.701
Wt. Sample Dry + Tare	54.524	53.768	55.501
Wt. Water	1.556	1.779	1.200
Tare Container	53.267	52.331	54.446
Wt. of Dry Soil	1.257	1.437	1.055
Moisture Content %	124	124	114

Shrinkage Limit

Trial No.			
Container No.			
Wt. Sample Wet + Tare			
Wt. Sample Dry + Tare			
Wt. Water			
Tare Container			
Wt. of Dry Soil W_o			
Moisture Content w%			
Vol. Container V			
Vol. Dry Soil Pat V_o			
Shrinkage Vol. $V-V_o$			
Shrinkage Limit w_s			

$$w_s = w\left(\frac{V-V_o}{W_o} \times 100\right)$$

Description of Sample:

Remarks:

DATA SHEET No. 20.

ANGULAR DEFORMATION IN 5/8" DRILL STEMS.

TORQUE Ft-lbs LENGTH Ft	40	80	120	160
4	5	12	20	30
6	10	20	25	35
8	12	28	42	58
10	14	30	45	58
12	15	34	55	75
14	18	37	60	85
16	19	42	70	105
18	20	47	75	110
20	25	64	95	130
22	30	65	100	142
24	35	75	115	155

DATA SHEET NO. 21

TABLE NO. 1

SUMMARY OF RESULTS OF ATTERBERG LIMITS

RUN ON SAMPLES OF DISTURBED MUSKEG FROM PEMBINA OIL FIELDS

Sample No.	Depth (Feet)	w%	Ash Content	Shear (#/sq.ft)	$w_l\%$	$w_p\%$	$w_s\%$	I_p	I_f	I_t
2	4	613	11	378	468	619	219	-	322	-
3	6	715	9	300	532	691	268	-	553	-
4	8	573	17	432	460	688	213	-	289	-
5	10	478	57	480	473	429	98	44	306	0.144
8	4	687	11	288	538	641	-	-	311	-
9	6	850	8	330	638	670	-	-	324	-
10	8	617	13	600	524	561	-	-	241	-
11	9'-6"	432	37	528	337	345	-	0	166	-
23	9'-3"	188	82	575	147	121	-	26	121	0.215

COMPUTATIONS SHEET NO 1
in conjunction with
DATA SHEETS NOS 1, 2, 3

Hole No.	Depth	Torque	Length of Drill Stem	Angular Deformation	Twist in Drill Stem	Angular Deformation in Soil	Shear Strength
1	(DET) V						
	1	45	2	70	4	66	270
	2	55	2	50	4	46	330
	4	63	6	60	14	46	378
	6	50	6	50	11	39	300
	8	72	10	80	27	53	432
	10	80	10	60	30	30	480
2	(DET) V						
	1	45	2	50	4	46	270
	2	45	2	50	4	46	270
	4	68	6	70	15	55	408
	6	55	6	60	12	48	330
	8	65	10	65	24	41	390
	10	70	10	70	26	44	420
3	(DET) V						
	1	55	2	60	4	56	330
	2	70	2	70	5	65	420
	4	75	6	60	17	43	450
	6	45	6	60	10	50	270
	8	75	10	70	28	42	450
	10	65	10	55	24	31	390
4	(DFI) D						
	1	65	2	50	5	45	390
	2	88	2	80	7	73	528
	4	50	6	55	11	44	300
	6	53	6	60	12	48	318
	8	82	10	70	31	39	492
	10	80	10	70	30	40	480
5	(DFI) D						
	1	67	2	65	5	60	402
	2	67	2	70	5	65	402
	4	48	6	55	11	44	288
	6	55	6	60	12	48	330
	8	100	10	80	37	43	600
	10	90	10	100	33	67	540
6	(DFI) D						
	1	60	2	55	5	50	360
	2	90	2	90	7	83	540
	4	50	6	55	11	44	300
	6	55	6	60	12	48	330
	8	98	10	70	36	34	588
	10	90	10	100	33	67	540
7	(DFI) C						
	1	117	2	100	9	91	702
	2	117	2	80	9	71	702
	4	105	6	70	24	46	630
	6	110	6	115	25	90	660
	8	140	10	120	52	68	700
8	(DFI) C						
	2	160	2	160	12	148	800
	4	170	6	100	39	61	850
	6	125	6	120	28	92	625
	8	155	10	125	58	67	775
10	(DFI) D						
	1	80	2	80	6	74	400
	2	100	2	90	8	82	500
	4	105	6	85	24	61	520
	6	80	6	55	18	37	400
	8	100	10	90	37	53	500
11	(DFI) D						
	1	75	2	65	6	59	375
	2	85	2	55	7	48	425
	4	130	6	120	29	91	650
	6	80	6	60	18	42	400
	8	85	10	80	32	48	425
	9	105	10	90	39	51	525
12	(DFI) D						
	1	75	2	70	6	64	375
	2	85	2	65	7	58	425
	4	95	6	85	21	64	475
	6	75	6	65	17	48	375
	8	60	10	65	22	43	300
	9	95	10	75	35	40	475
13	(DFI) C						
	1	145	2	100	11	89	1030
	2½	155	6	140	35	105	775
	4	160	6	115	36	79	800
	6	100	6	80	22	58	500
	8	145	10	130	54	76	805
14	(DFI) C						
	1½	160	2	115	12	103	800
	2½	170	6	140	39	101	850
	4	160	6	115	36	79	800
	6	130	6	105	27	76	650
	8	145	10	130	50	80	750

BLOCK 1, TSD 6, SEC 15-19-8-E

SOIL TEST FIELD SHEET NO 2
in conjunction with
DATA SHEETS Nos [illegible]

Hole No.	Depth	Torque	Length of Drill Stem	Angular Deformation	Twist in Drill Stem	Angular Deformation in Soil	Shear Strength
1 (BDI)		V					
	1	65	2	60	5	55	325
	2	65	2	70	5	65	325
	4	80	6	80	18	62	400
	6	70	6	75	16	59	350
	8	85	10	80	32	48	425
2 (BDI)		V					
	1	40	2	70	3	67	200
	2	37	2	55	3	52	185
	4	68	6	60	15	45	340
	6	70	6	75	16	59	350
	8	75	10	90	28	62	375
	9	105	10	90	38	51	525
3 (BDI)		V					
	1	35	2	65	3	62	175
	2	60	2	70	5	65	300
	4	75	6	60	17	43	375
	6	75	6	60	17	43	375
	8	85	10	90	32	58	425
	9	115	10	100	43	57	575
4 (BDI)		C					
	1	115	2	90	9	81	575
	2½	130	6	80	29	51	650
	4	120	6	100	27	73	600
	6	100	10	75	37	38	500
5 (BDI)		C					
	1	112	2	80	9	71	560
	2½	175	6	120	40	80	875
	4	110	6	100	25	75	550
	6	100	10	80	37	43	500
6 (BDI)		C					
	1	125	2	120	10	110	780
	2½	135	6	75	30	45	675
	4	120	6	100	27	73	600
	6	115	10	85	43	42	575
7 (BDI)		D					
	1	65	2	65	5	60	325
	2	75	2	60	6	54	375
	4	155	6	120	35	85	775
	6	80	6	55	18	37	400
	8	105	10	90	39	51	525
8 (BDI)		D					
	1	85	2	65	7	58	425
	2	75	2	55	6	49	375
	4	110	6	90	25	65	550
	6	80	6	55	18	37	400
	8	110	10	100	41	59	550
9 (BDI)		D					
	1	82	2	75	6	69	410
	4	75	6	75	17	58	375
	6	85	6	60	19	41	425
	8	105	10	105	39	66	660

[illegible] 1, TSB 2, SEC 5,-[illegible]

Hole No.	Depth	Torque	Length of Drill Stem	Angular Deformation	Twist in Drill Stem	Angular Deformation in Soil	Shear Strength
1 (BDI)		V					
	1	30	2	50	2	48	150
	2	55	2	55	4	51	275
	4	65	6	70	15	55	325
	6	65	6	60	15	45	325
	8	100	10	100	37	63	500
	[illegible]-3"	120	10	100	45	55	600
2 (BDI)		V					
	1	30	2	60	2	58	150
	2	70	2	70	5	65	350
	4	65	6	75	15	60	325
	6	55	6	55	12	43	275
	8	80	10	85	30	55	400
	9½	115	10	90	43	47	575
3 (BDI)		V					
	1	30	2	60	2	58	150
	2	50	2	50	4	46	250
	4	60	6	60	13	47	300
	6	70	6	65	16	49	350
	8	100	10	100	37	63	500
	9½	135	10	110	50	60	675
4 (BDI)		C					
	½	120	2	80	9	71	600
	2½	112	6	75	25	50	560
	4½	95	6	90	21	69	475
	6½	85	10	80	32	48	425
	8	120	10	120	45	75	600
	8-3"	115	10	120	43	77	575
5 (BDI)		C					
	1	125	2	100	10	90	625
	2	135	2	80	11	69	675
	4	75	6	70	17	53	375
	6	85	6	75	19	56	425
	8	110	10	115	41	74	550
7 (BDI)		C					
	1	135	2	95	11	84	675
	2	110	2	70	8	62	550
	4	90	6	95	20	75	450
	6	85	6	75	19	56	425
	8	120	10	130	45	85	600
8 (BDI)		V - cleared					
	1	28	2	60	2	58	140
	2	55	2	70	4	66	275
	4	130	6	95	29	66	650
	6	70	6	75	16	59	350
	8	80	10	85	30	55	400
	9½	93	10	80	35	45	465
9 (BDI)		V - cleared					
	1	23	2	55	2	53	115
	2	40	2	55	3	52	200
	4	75	6	105	17	88	375
	7	70	6	90	16	74	350
	8	55	10	65	20	45	275
	9½	100	10	90	37	53	500
10 (BDI)		V - cleared					
	2	55	2	60	4	56	275
	4	55	6	75	12	63	275
	[illegible]	[illegible]	10	100	35	65	[illegible]
	[illegible]	[illegible]	10	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	10	[illegible]	[illegible]	42	[illegible]

PLATE NO. 1

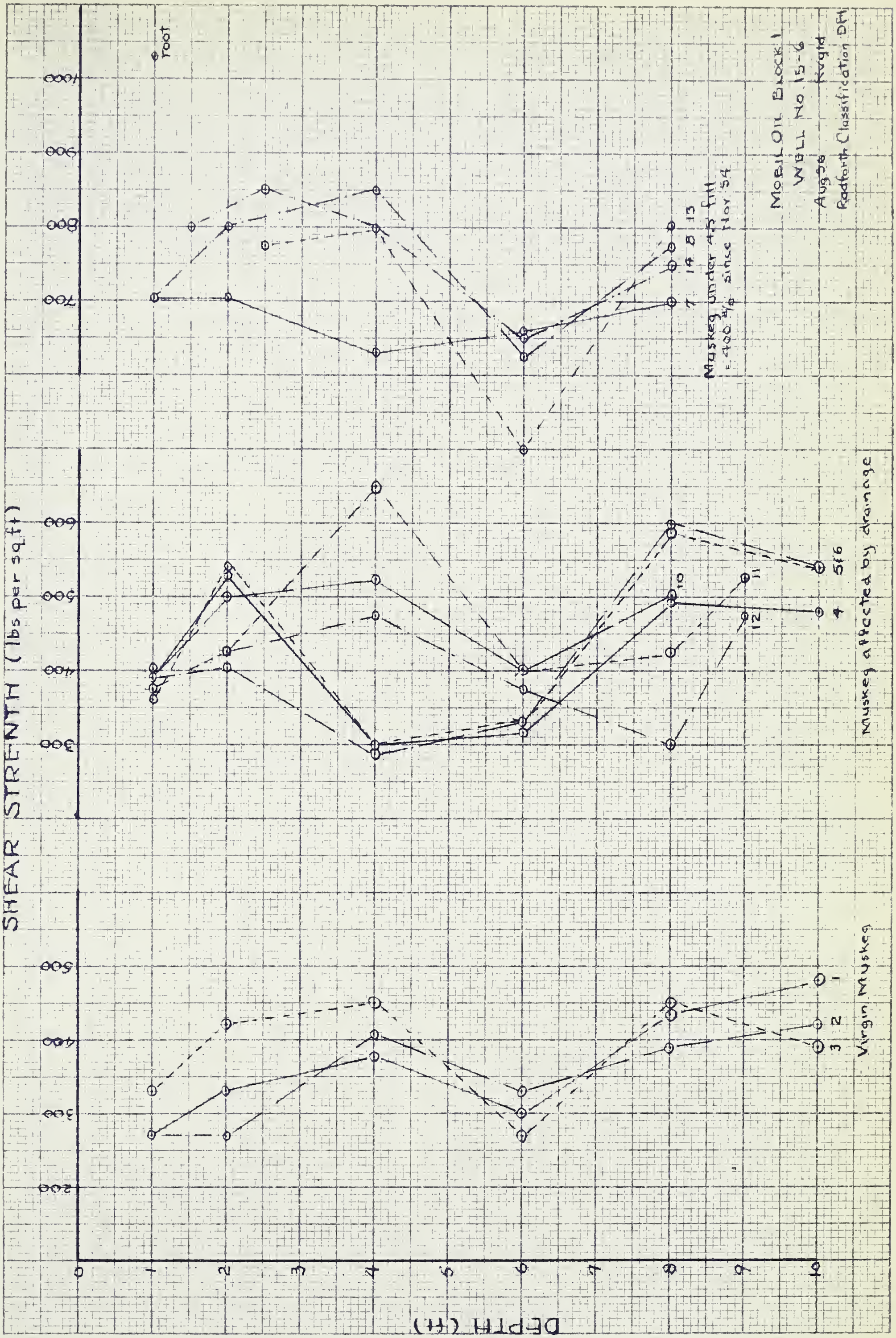

SHEAR STRENTH (lbs per sq ft)
DEPTH (ft)
200
300
400
500
300
400
500
600
700
800
900
1000
0
1
2
3
4
5
6
7
8
9
10
root
7 14 8 13
Muskeg under 4.5 fill
= 400 #/□ since Nov 54
MOBIL OIL BLOCK 1
WELL No. 15-6
Aug 56 Krgtd
Radforth Classification DFH
10
11
12
5 & 6
4
Muskeg affected by drainage
1
2
3
Virgin Muskeg

PLATE NO 2.

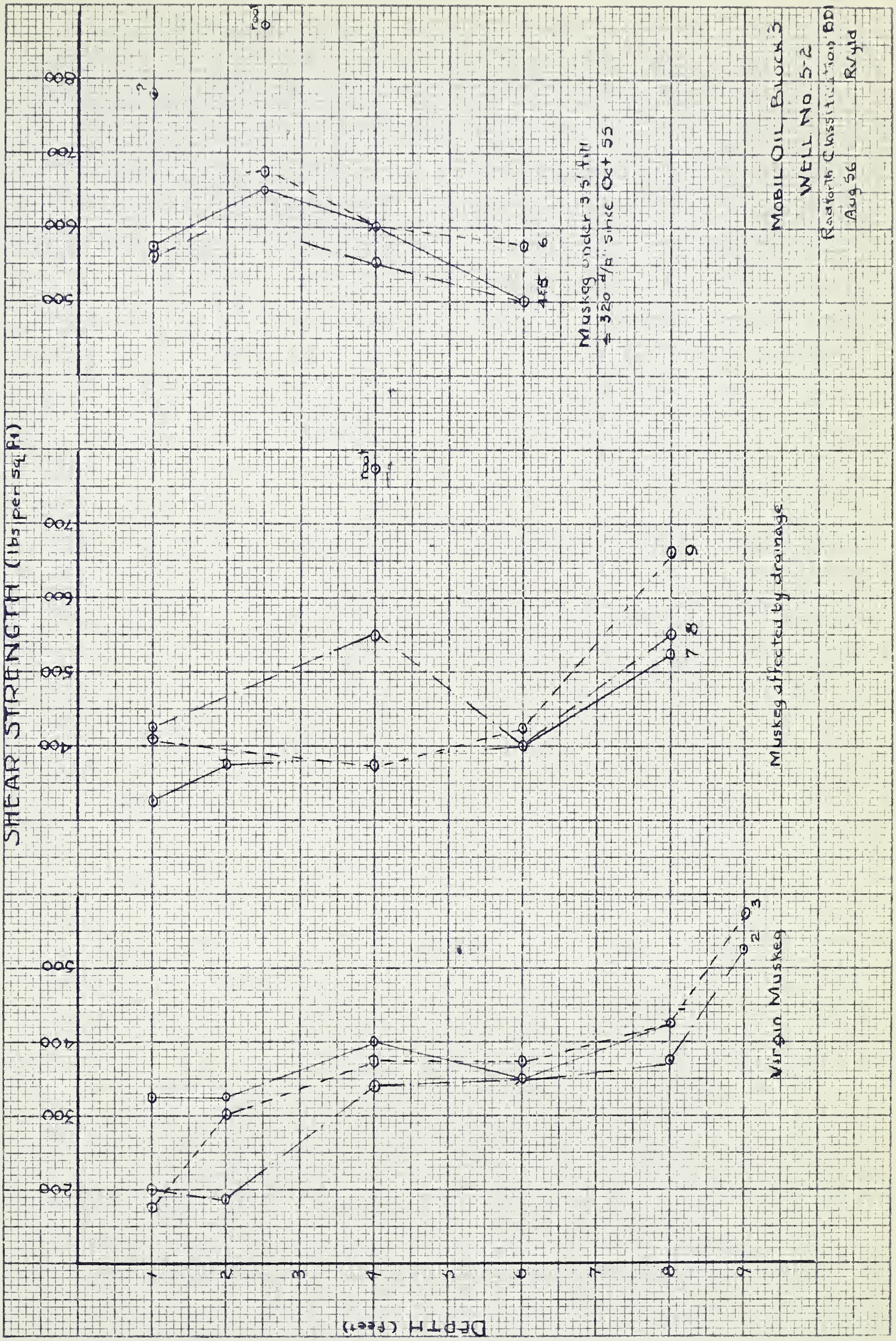

SHEAR STRENGTH (lbs per sq ft)
DEPTH (feet)
1
2
3
4
5
6
7
8
9
200
300
400
500
400
500
600
700
500
600
700
800
Virgin Muskeg
2
3
Muskeg affected by drainage
7
8
9
root
Muskeg under 3.5' fill
+ 320 #/ft² since Oct 55
4&5
6
root
?
MOBIL OIL BLOCK 3
WELL NO 5-2
Radforth Classification BDI
Aug 56
Rv/yld

PLATE NO. 3.

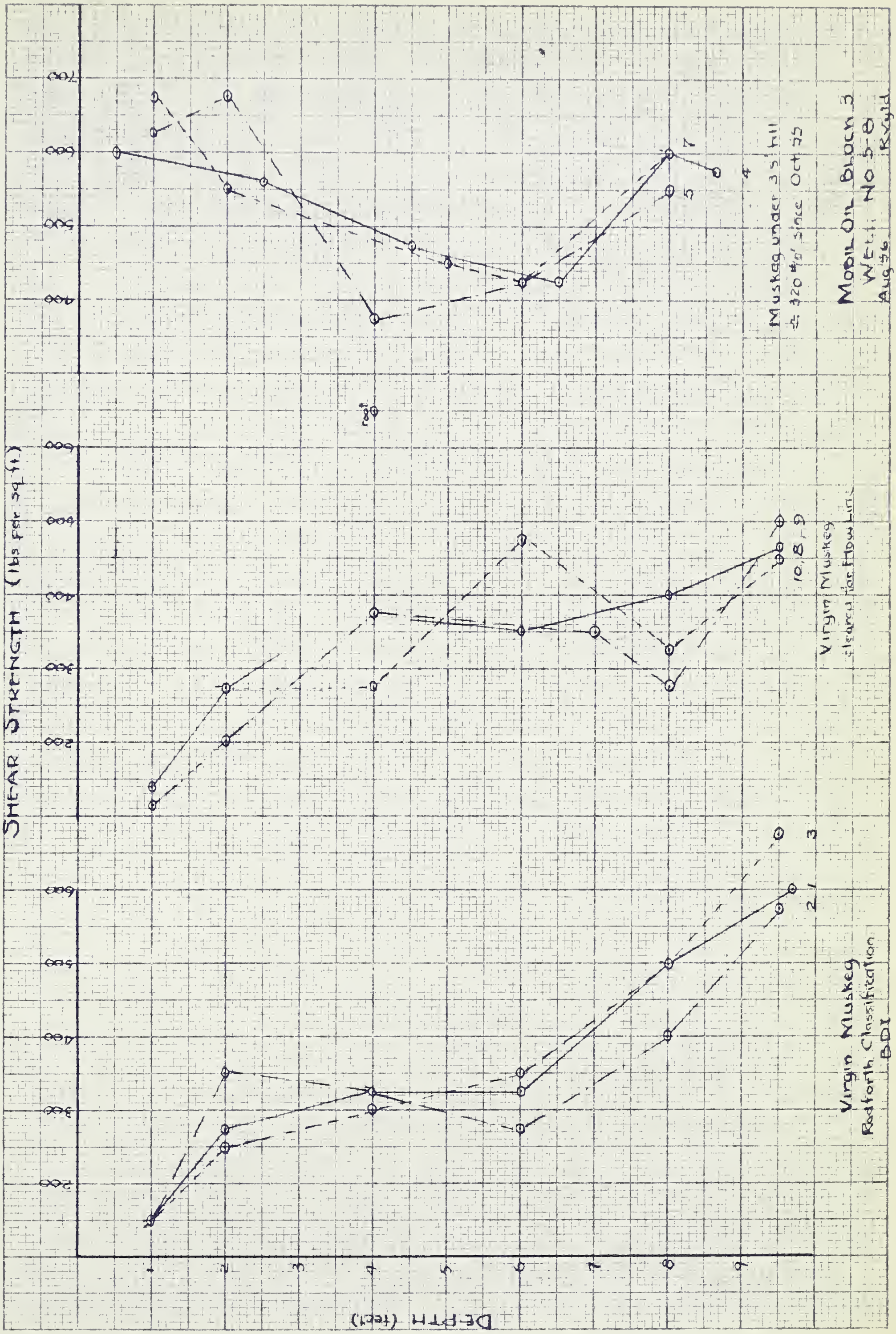

SHEAR STRENGTH (lbs per sq ft)
DEPTH (feet)
1
2
3
4
5
6
7
8
9
200
300
400
500
600
200
300
400
500
600
400
500
600
700
root
7
5
4
10, 8, 9
3
2 1
Muskeg under 3.5' fill
± 320 #/□' since Oct 55
Mobil Oil Block 3
Well No 5-8
Aug 56 Rkyld
Virgin Muskeg
cleared for Flow Line
Virgin Muskeg
Radforth Classification
BDI

PLATE NO. 4

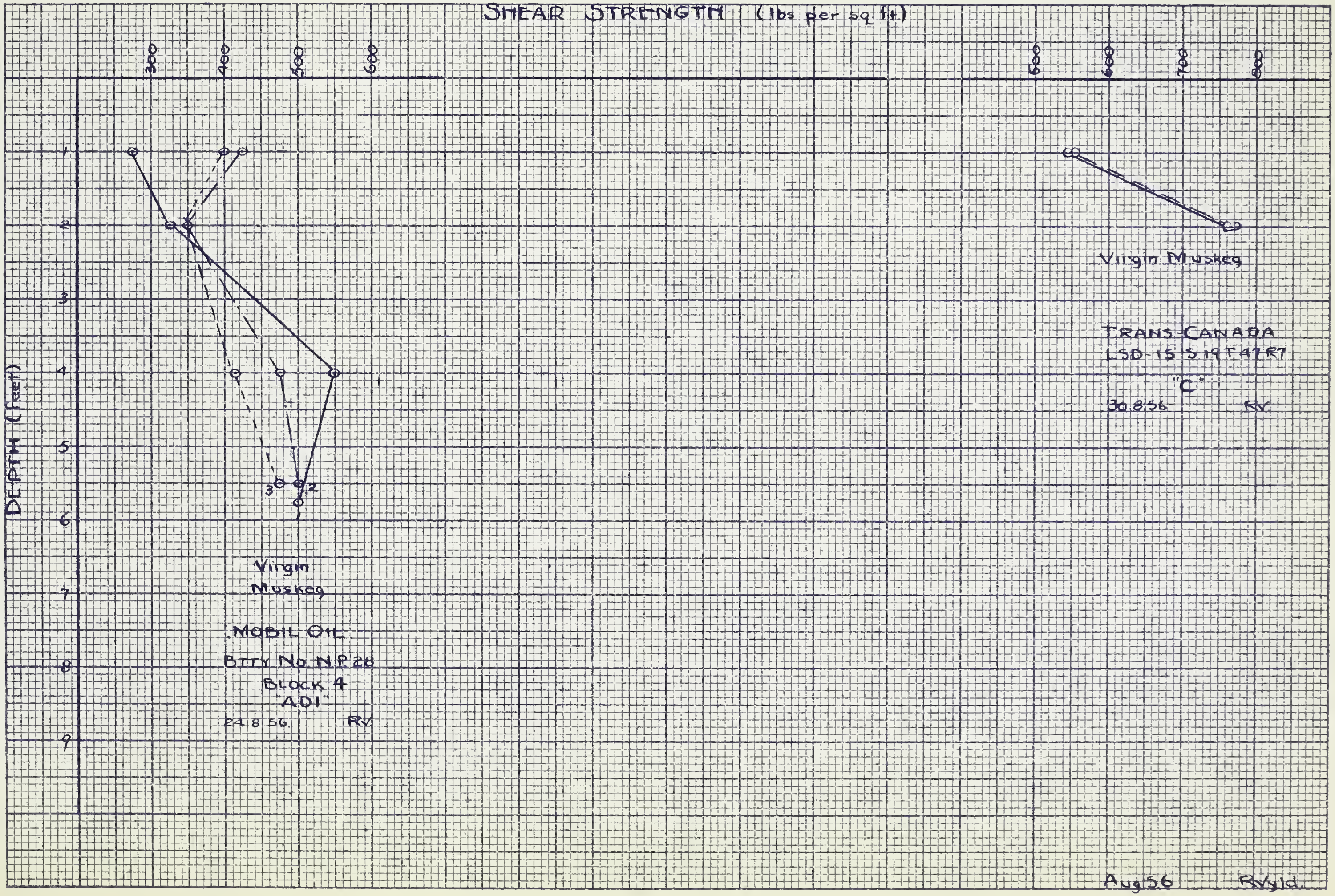
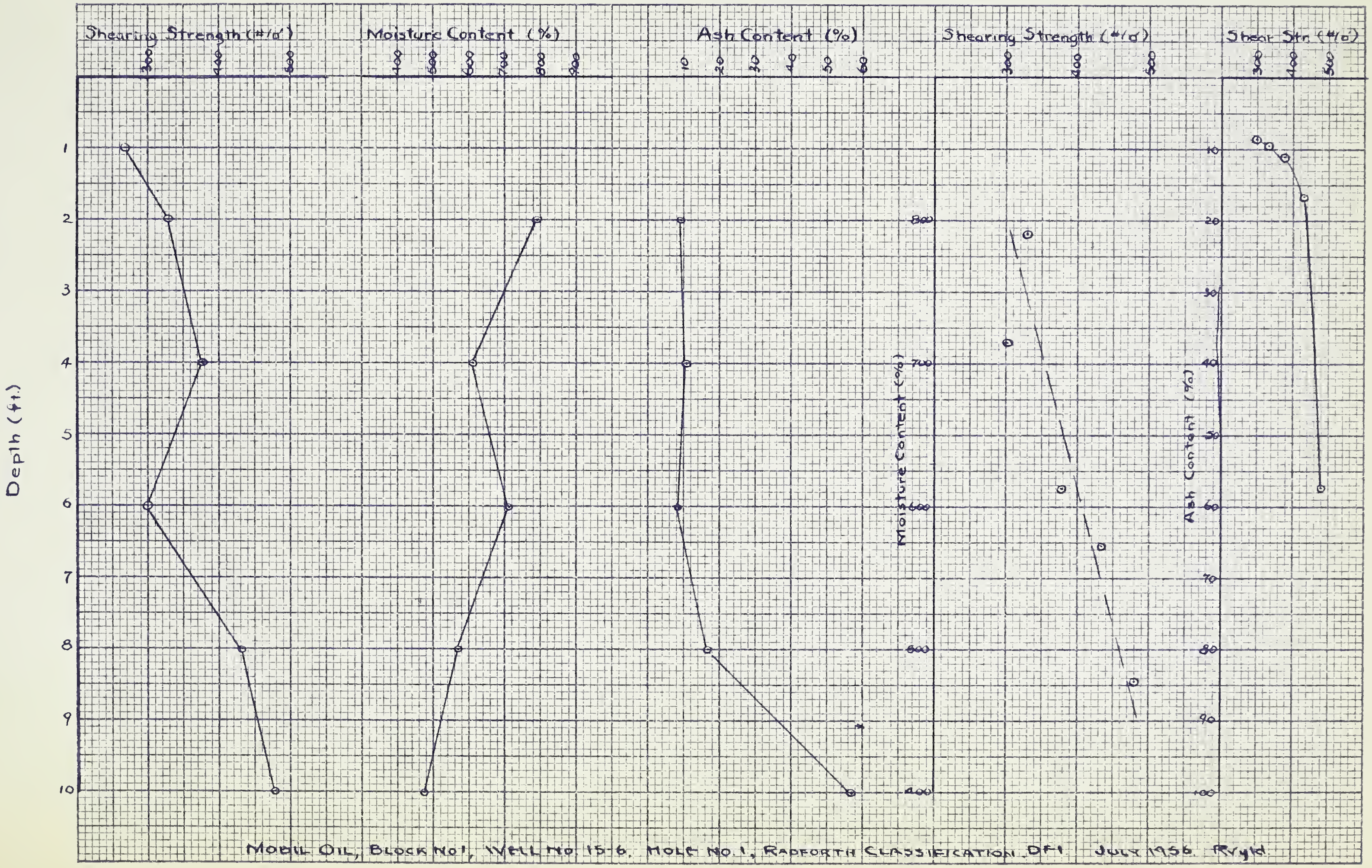

SHEAR STRENGTH (lbs per sq ft.)
300
400
500
600
500
600
700
800
DEPTH (Feet)
1
2
3
4
5
6
7
8
9
3
2
Virgin Muskeg
MOBIL OIL
BTTY No. N.P. 28
BLOCK 4
A.D.I.
24.8.56
RV
Virgin Muskeg
TRANS CANADA
LSD-15 S 19 T 47 R7
"C"
30.8.56
RV
Aug 56
RV yld.

PLATE No 5

RELATIONSHIPS BETWEEN SHEARING STRENGTHS, ASH & MOISTURE CONTENTS & DEPTH

VIRGIN MUSKEG.

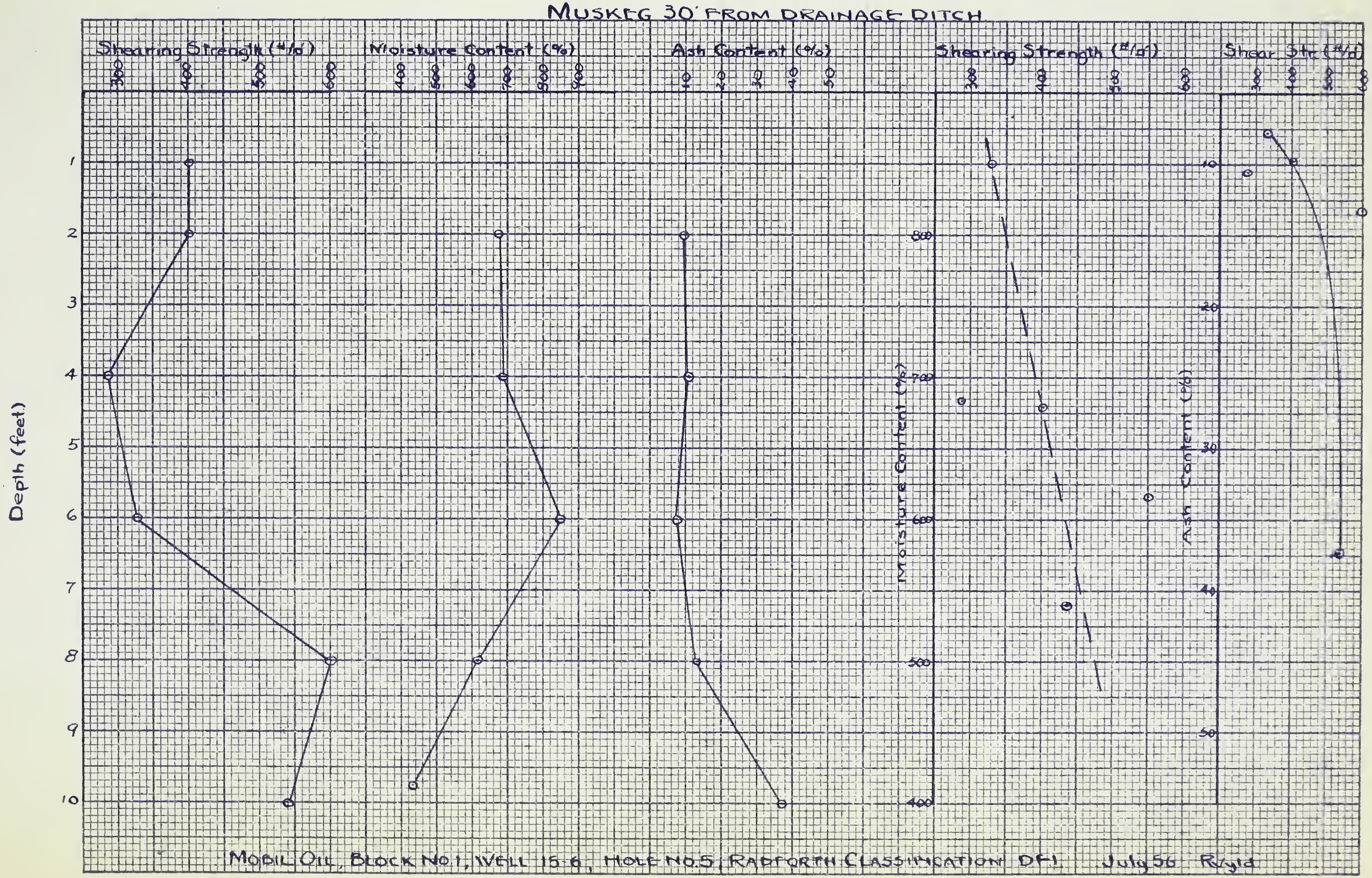


MOBIL OIL, BLOCK NO 1, WELL NO. 15-6. HOLE NO. 1, RADFORTH CLASSIFICATION DFI JULY 1956. RVyld.

PLATE No 6.

RELATIONSHIPS BETWEEN SHEARING STRENGTHS, ASH & MOISTURE CONTENTS & DEPTH

MUSKEG 30' FROM DRAINAGE DITCH

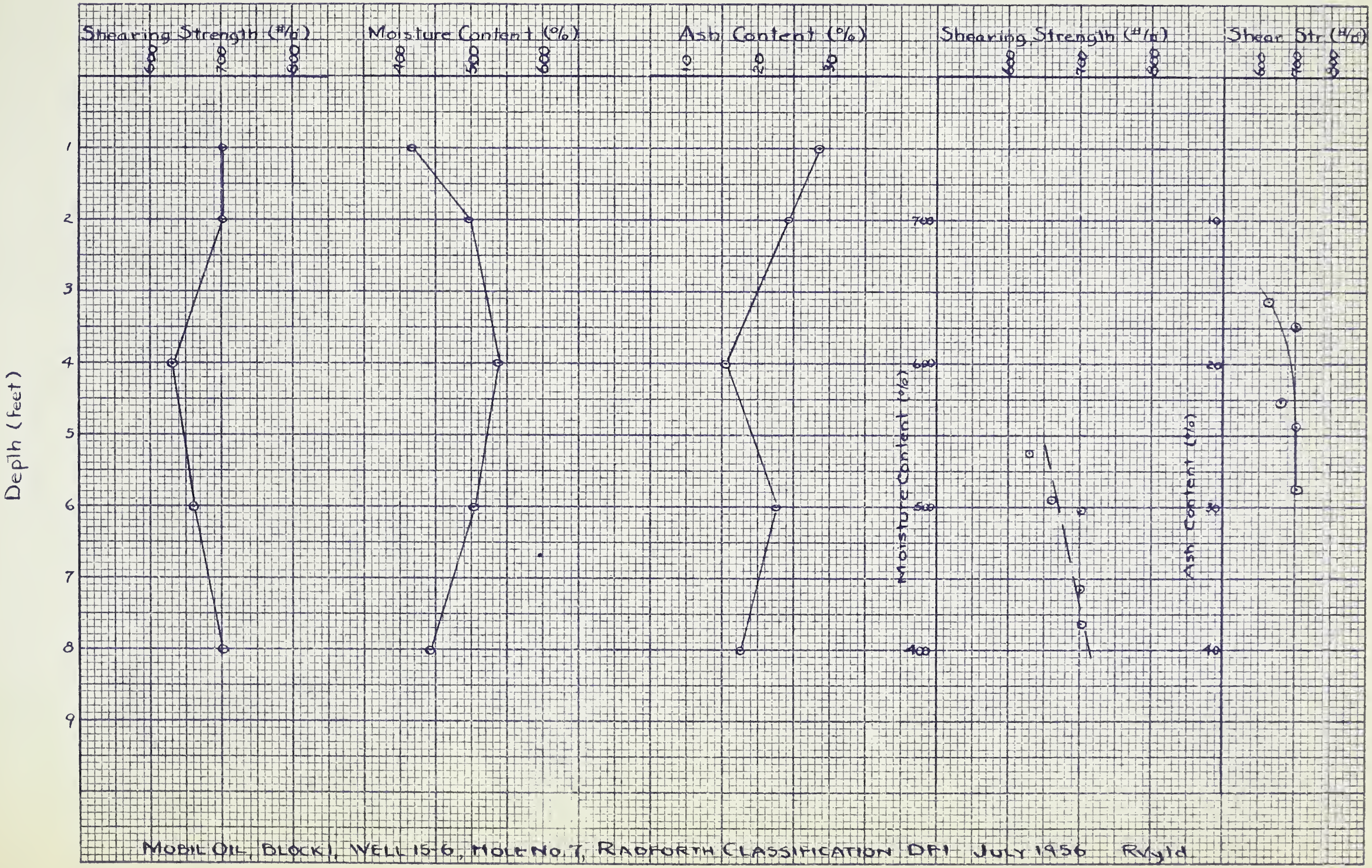


MOBIL OIL, BLOCK No 1, WELL 15-6, HOLE No.5, RADFORTH CLASSIFICATION DF1 July 56 RYJd

PLATE No 7

RELATIONSHIPS BETWEEN SHEARING STRENGTHS, ASH & MOISTURE CONTENTS & DEPTH.

MUSKEG CONSOLIDATED UNDER 400 #/□' FOR 21 MONTHS

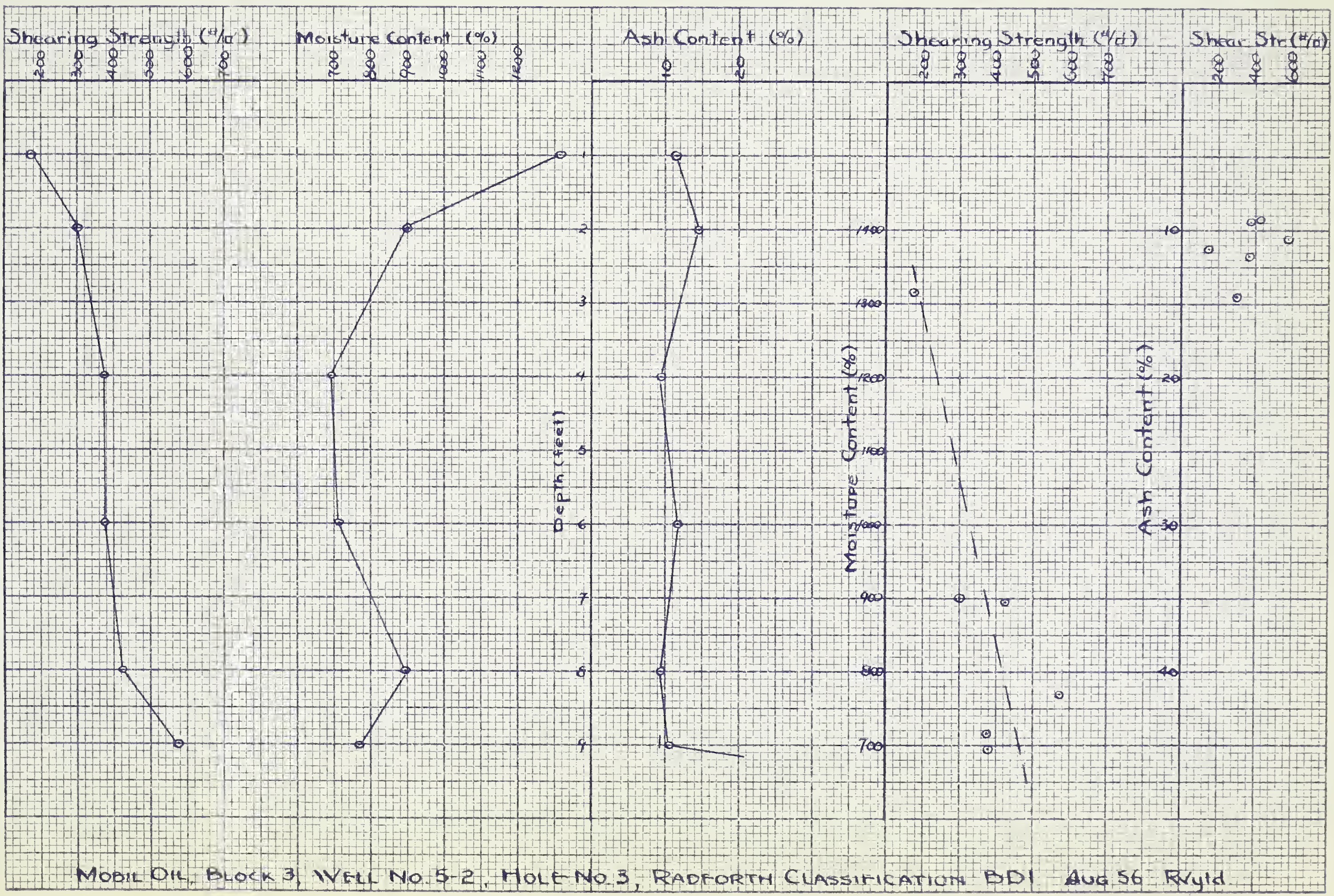


MOBIL OIL, BLOCK 1, WELL 15-6, HOLE No. 7, RADFORTH CLASSIFICATION DFI JULY 1956 RVyld

PLATE NO 8.

RELATIONSHIPS BETWEEN SHEARING STRENGTHS, ASH & MOISTURE CONTENTS & DEPTH

VIRGIN MUSKEG



MOBIL OIL, BLOCK 3, WELL NO. 5-2, HOLE NO. 3, RADFORTH CLASSIFICATION BDI AUG 56 RVyld

PLATE NO. 9.

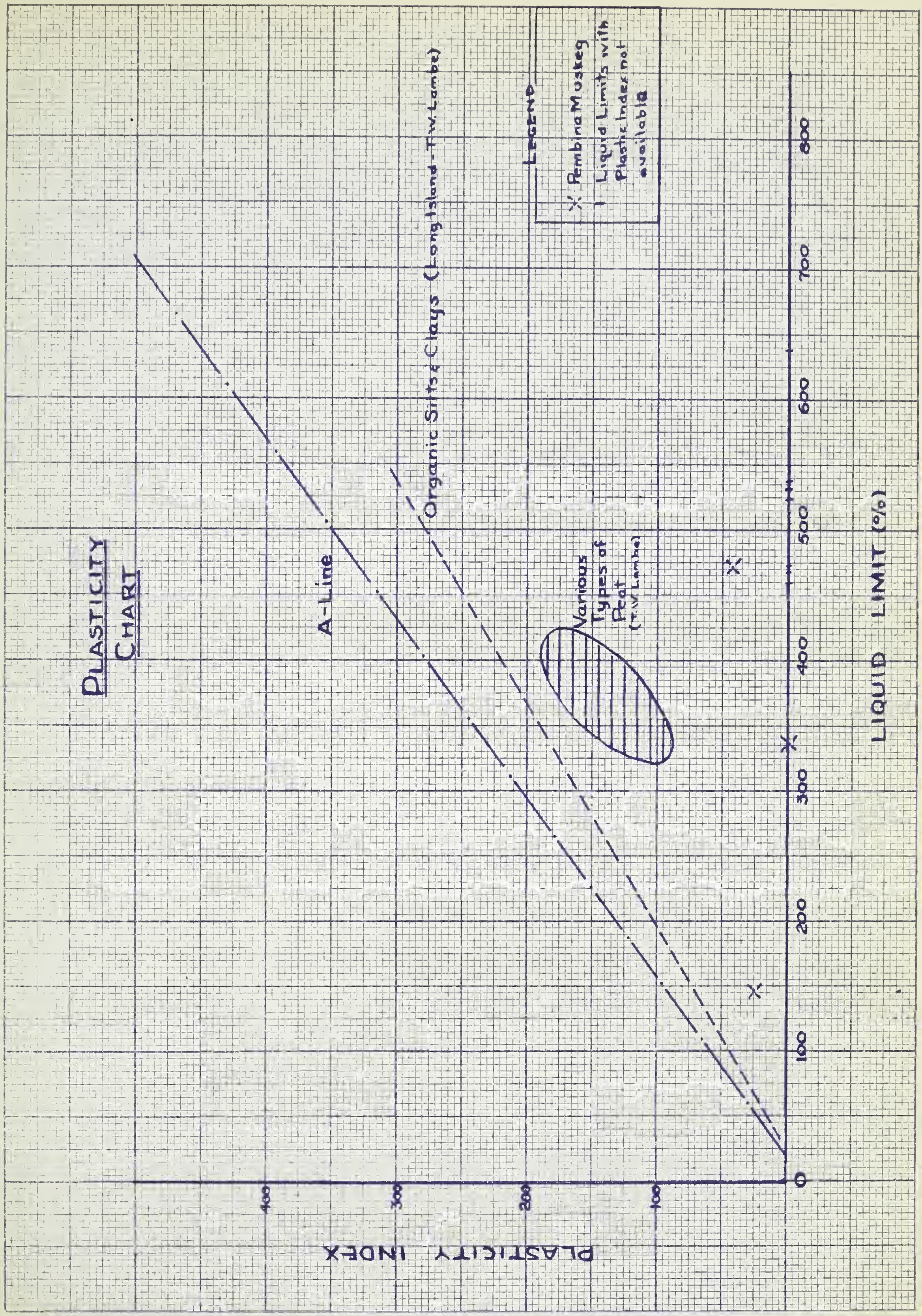
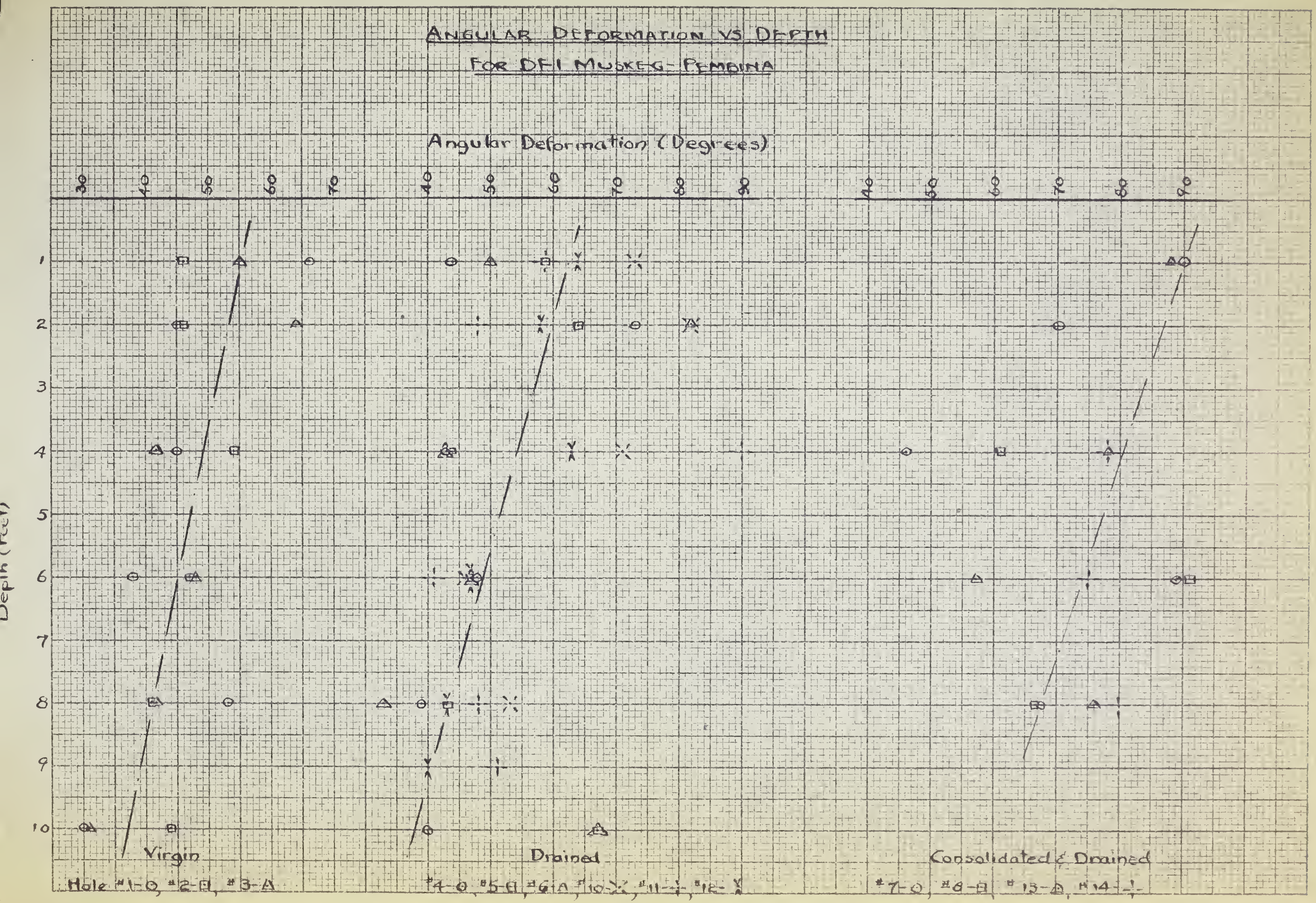

PLASTICITY CHART
A-Line
Organic Silts & Clays (Long Island - T.W. Lambe)
Various Types of Peat (T.W. Lambe)
LEGEND
X Pembina Muskeg
I Liquid Limits with Plastic Index not available
LIQUID LIMIT (%)
PLASTICITY INDEX
0
100
200
300
400
500
600
700
800
100
200
300
400

PLATE NO. 10.

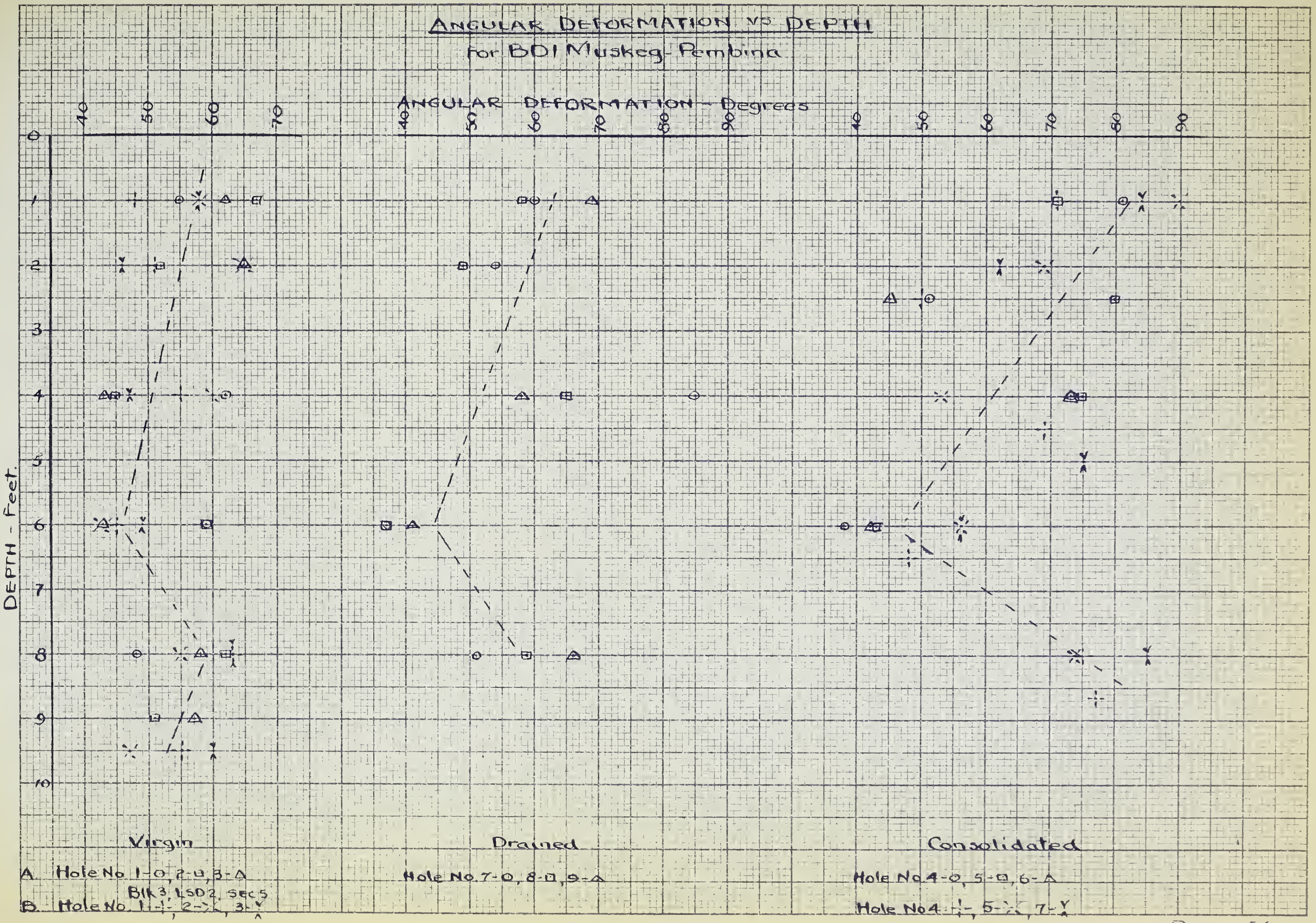


ANGULAR DEFORMATION VS DEPTH

FOR DFI MUSKEG-PEMBINA

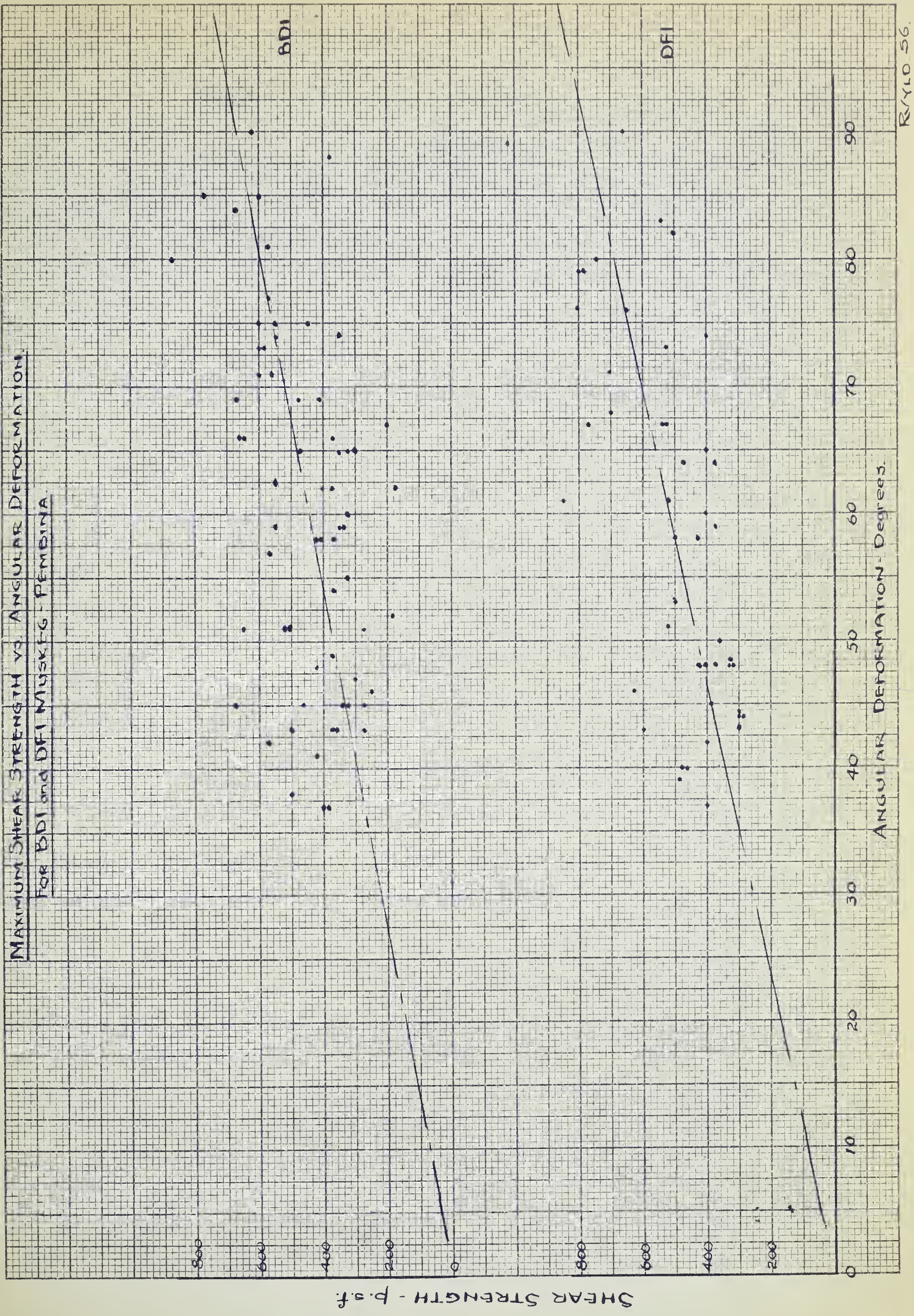
RVYLD 54

PLATE No 11.



ANGULAR DEFORMATION vs DEPTH
for BDI Muskeg-Pembina

PLATE No 12.



MAXIMUM SHEAR STRENGTH vs. ANGULAR DEFORMATION

FOR BDI and DFI MUSKEG - PEMBINA.

PLATE No 13.

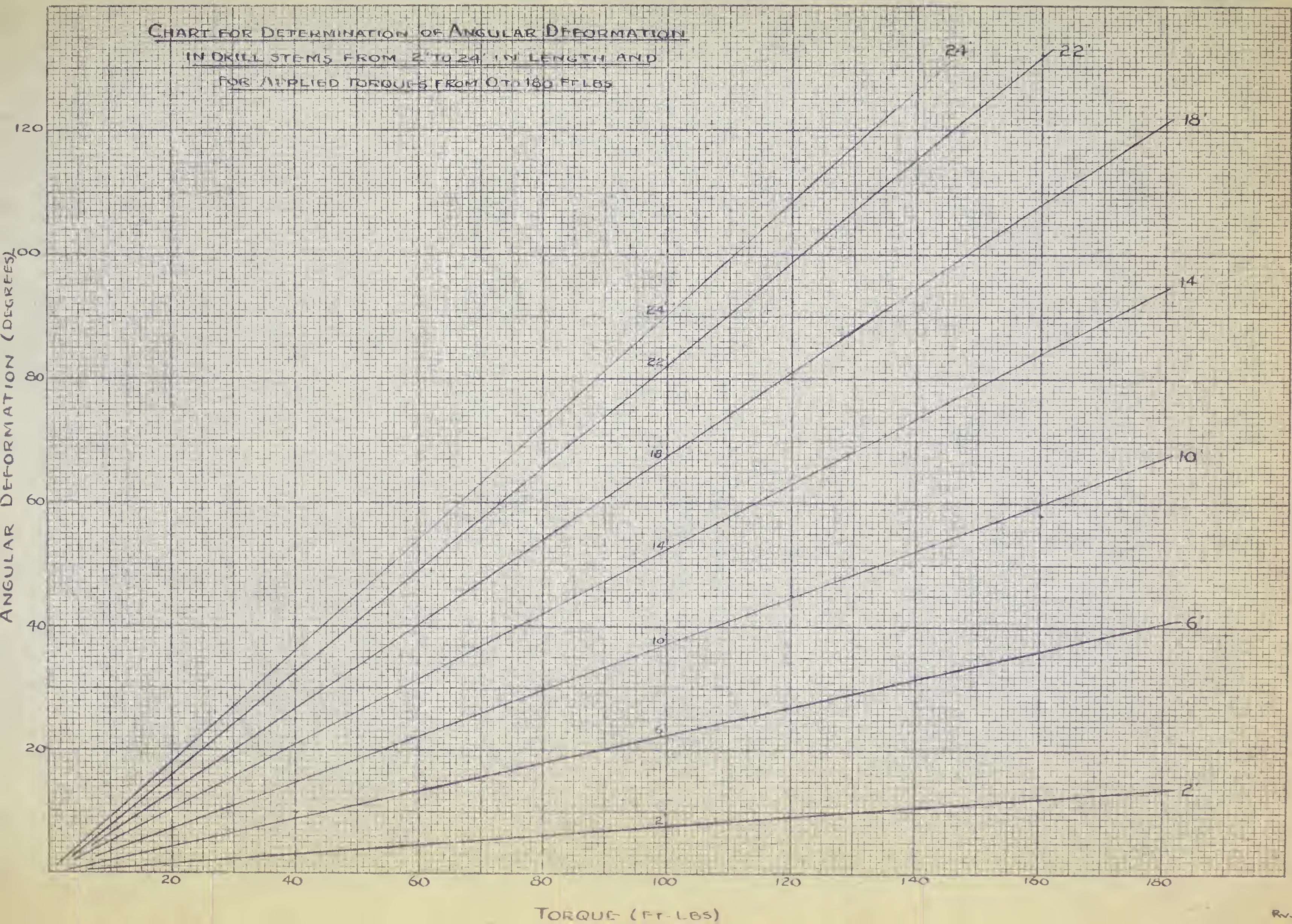


CHART FOR DETERMINATION OF ANGULAR DEFORMATION
IN DRILL STEMS FROM 2' TO 24' IN LENGTH AND
FOR APPLIED TORQUES FROM 0 TO 180 FT LBS

Rvyld.

PLATE #14

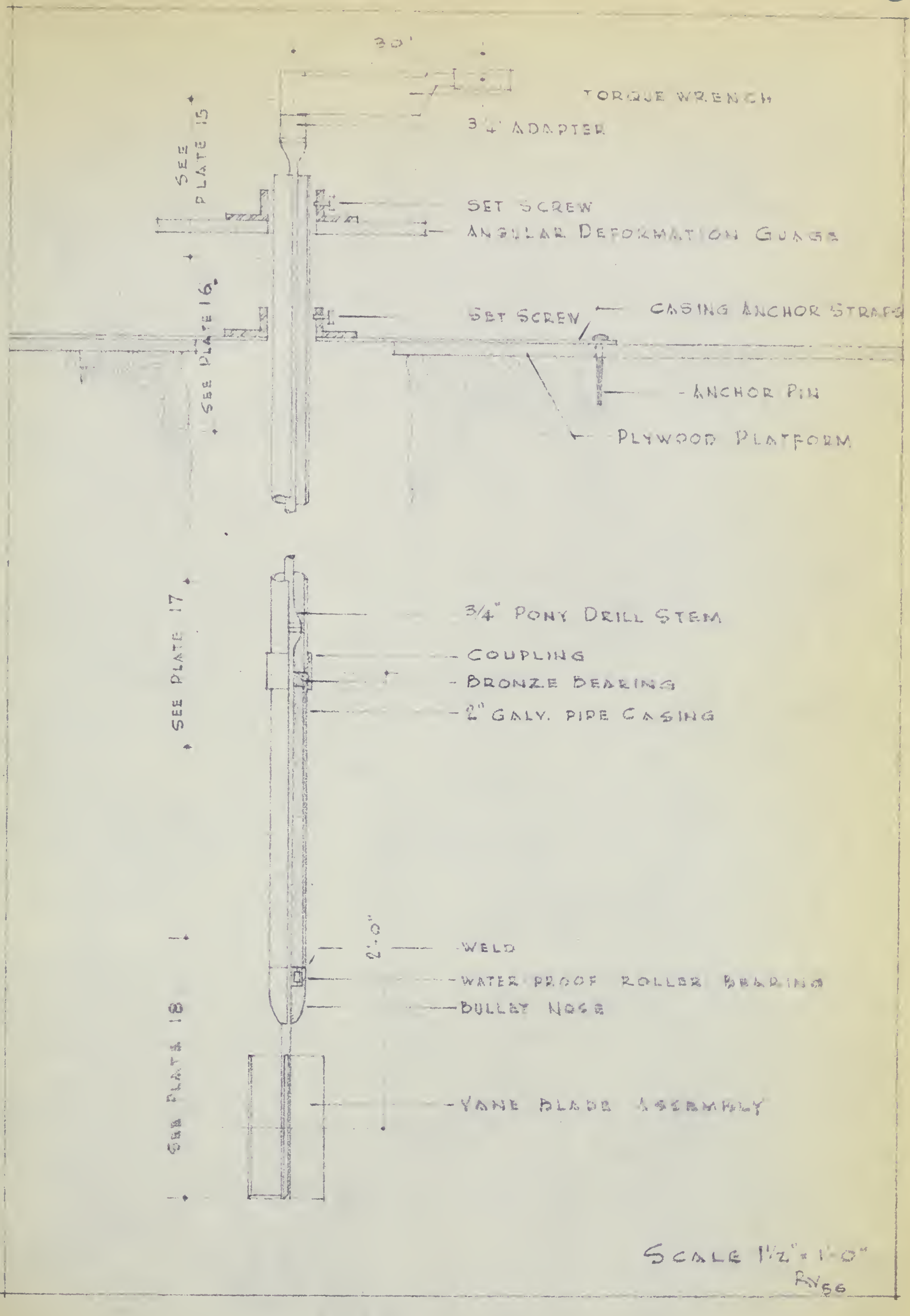
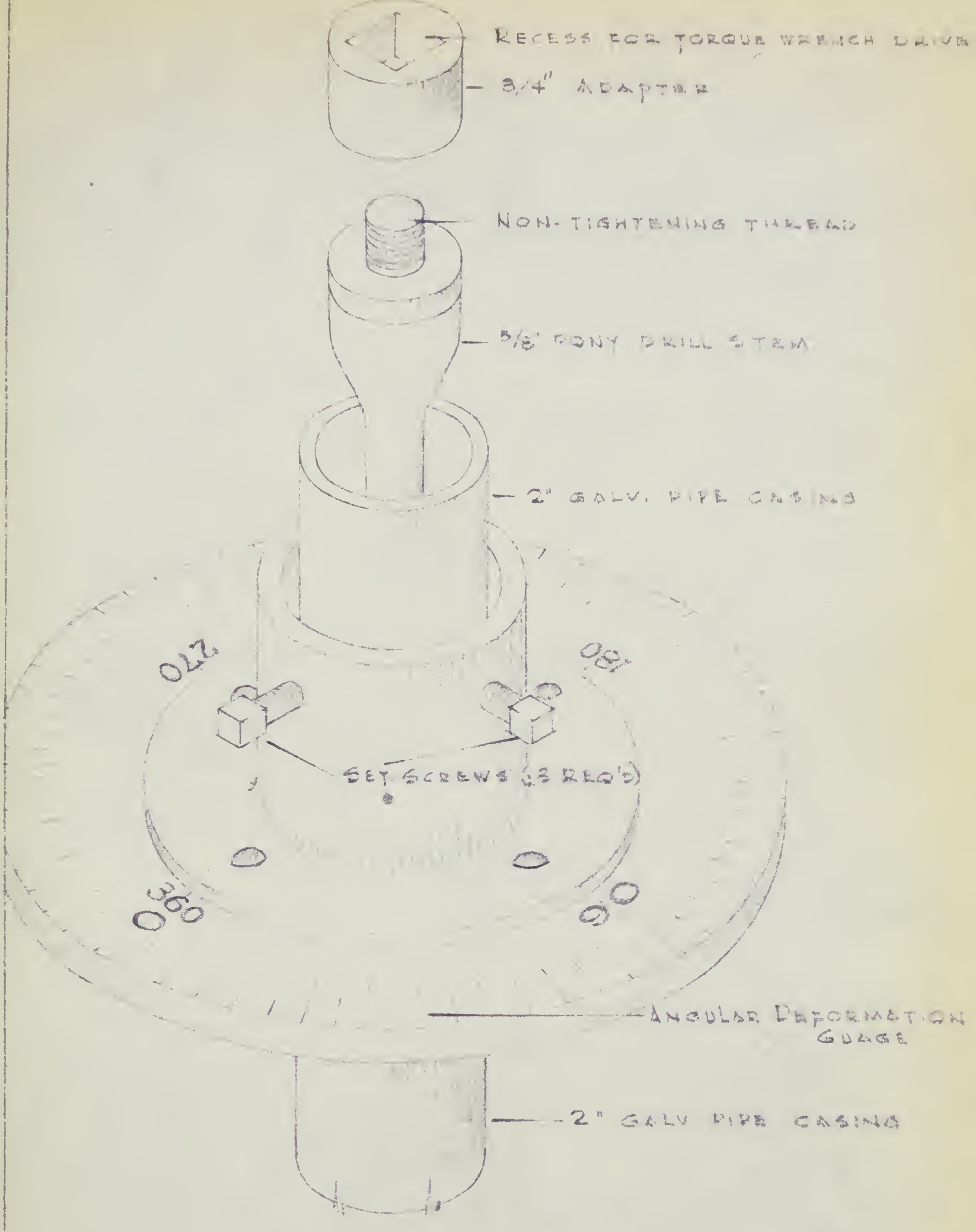

30'
TORQUE WRENCH
3/4" ADAPTER
SEE PLATE 15
SET SCREW
ANGULAR DEFORMATION GUAGE
SEE PLATE 16
SET SCREW
CASING ANCHOR STRAPS
ANCHOR PIN
PLYWOOD PLATFORM
SEE PLATE 17
3/4" PONY DRILL STEM
COUPLING
BRONZE BEARING
2" GALV. PIPE CASING
2'-0"
WELD
WATER PROOF ROLLER BEARING
BULLET NOSE
SEE PLATE 18
VANE BLADE ASSEMBLY
SCALE 1½" = 1'-0"
RV 56

PLATE #15



SCALE 1/2 FULL SIZE

R.V
58

PLATE #16

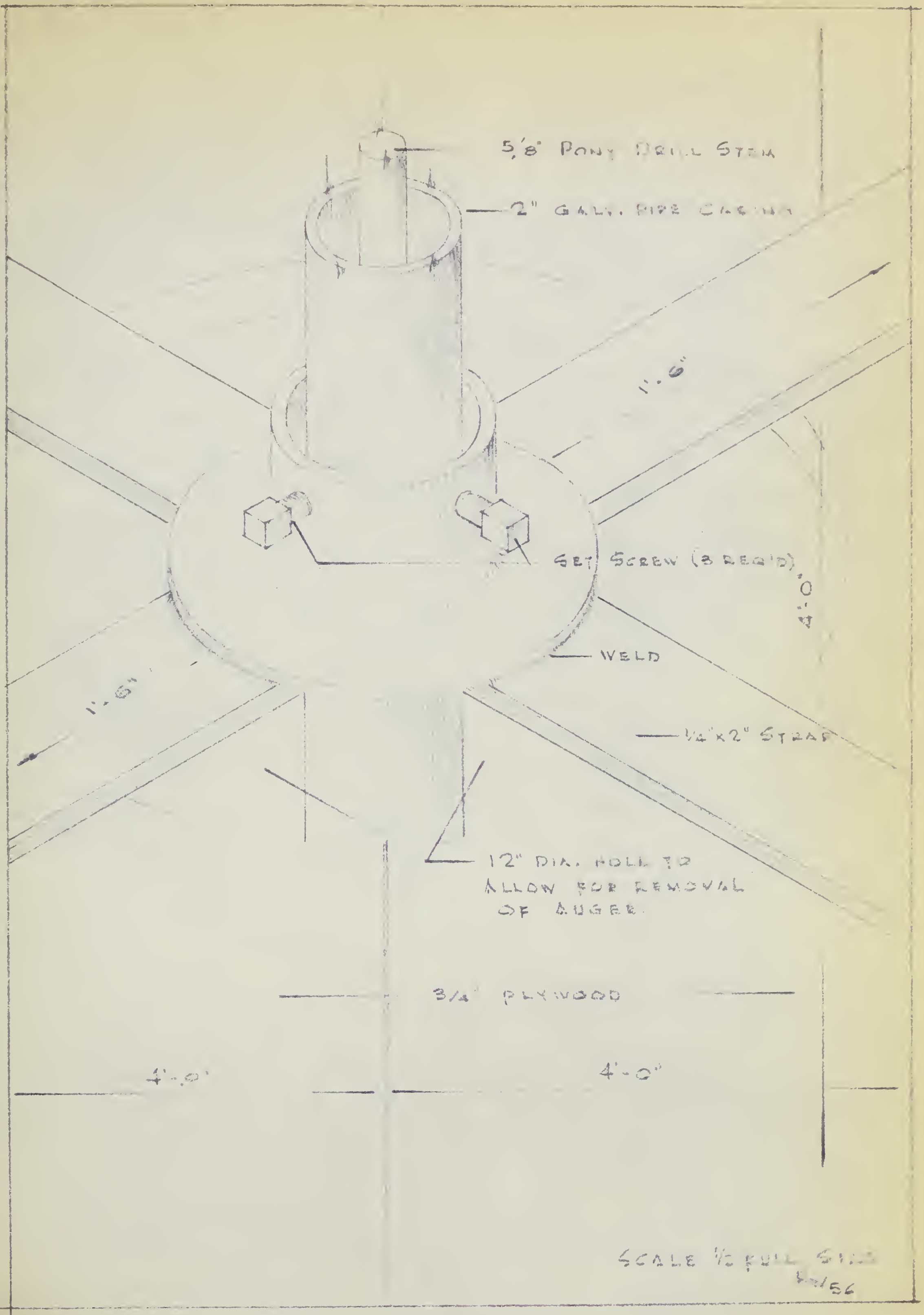
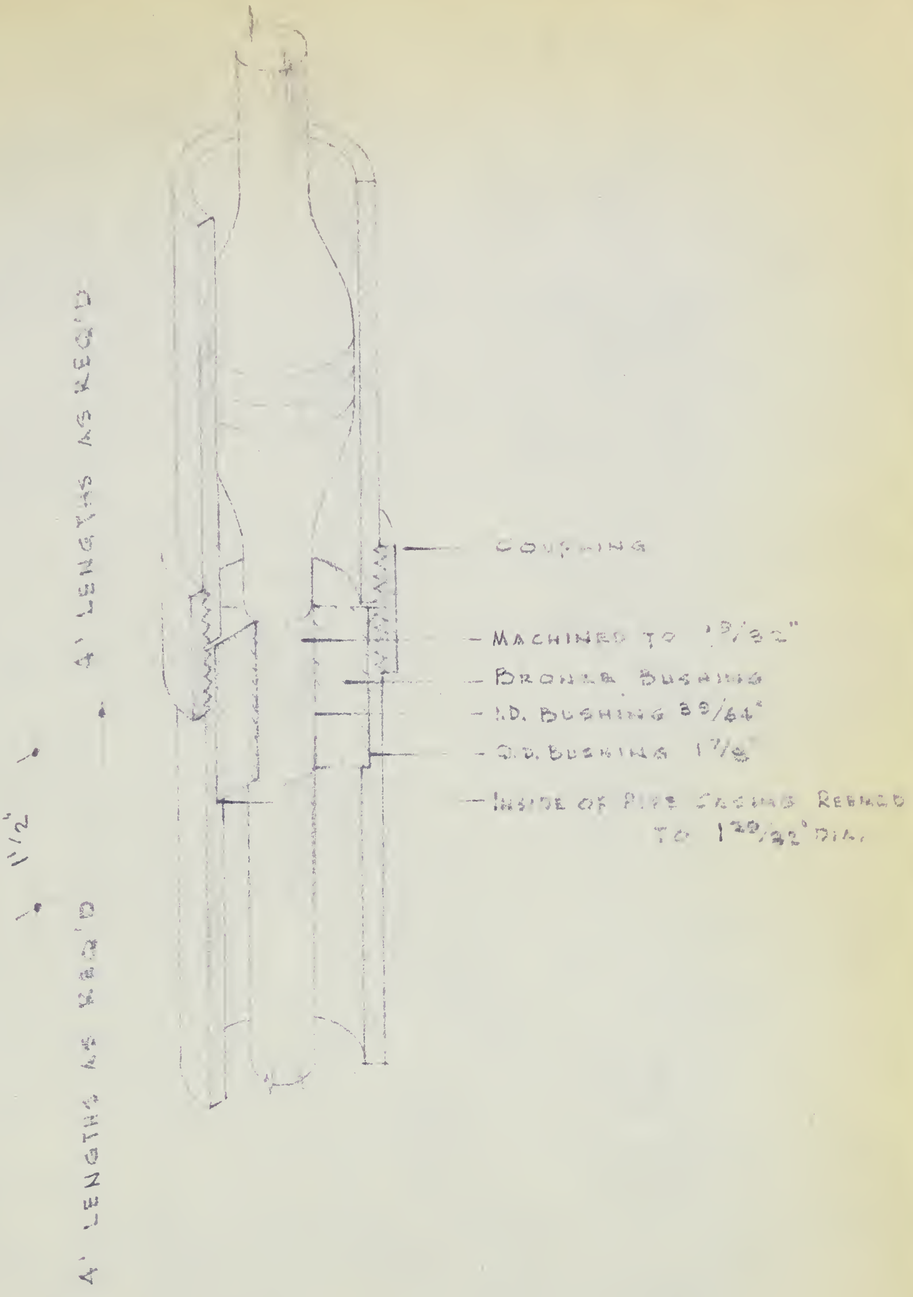
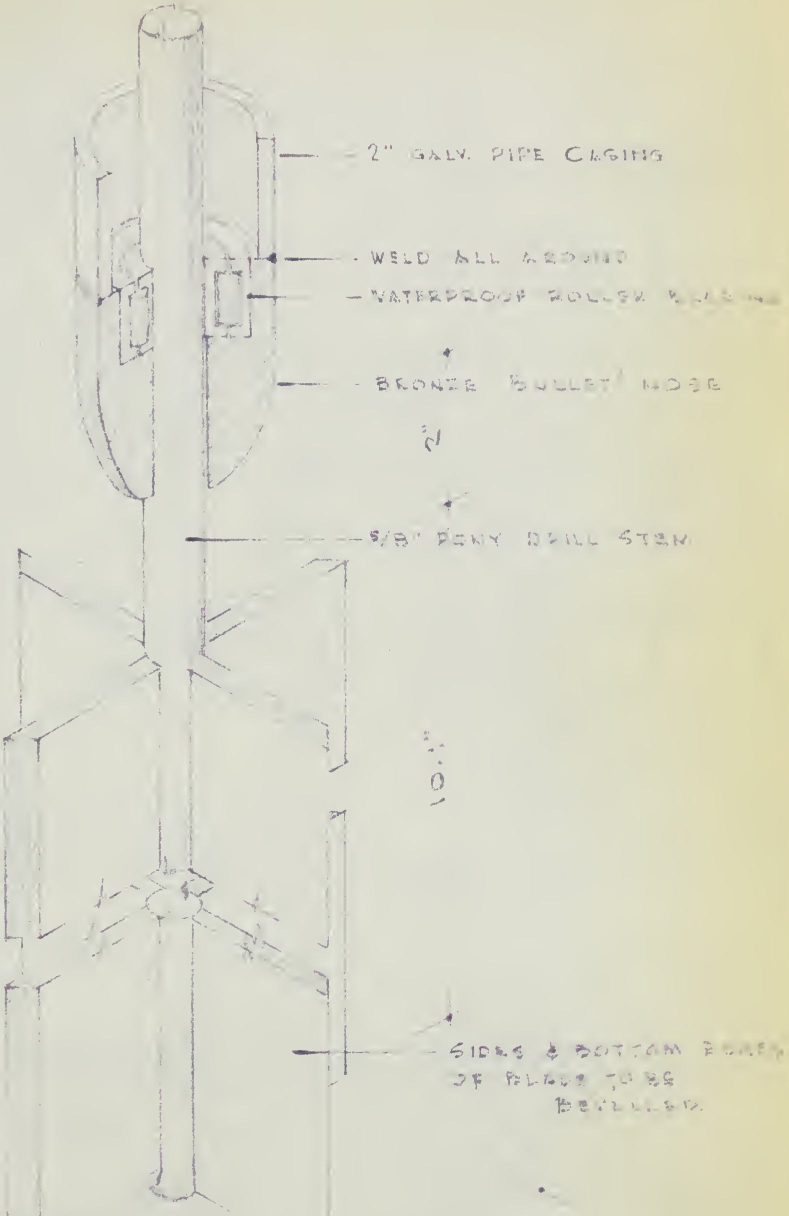

5/8" Pony Drill Stem
2" Galv. Pipe Casing
1'-6"
Set Screw (3 Req'd)
4'-0"
Weld
1'-6"
1/4"x2" Strap
12" Dia. Hole to Allow for Removal of Auger
3/4" Plywood
4'-0"
4'-0"
Scale 1/2 Full Size
4-/56

PLATE #17



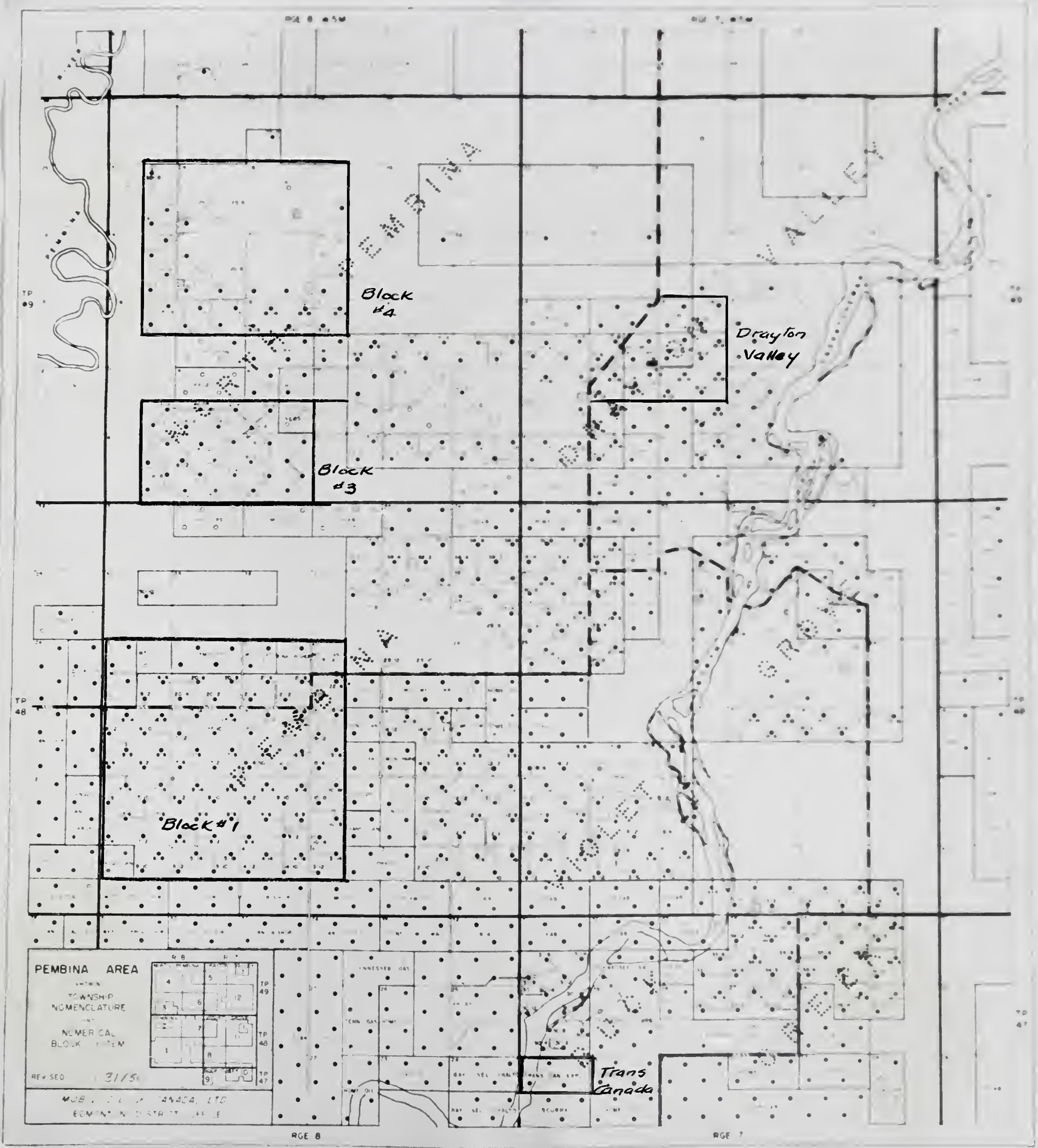
SCALE ½ FULL SIZE
RS/56

PLATE #16



SCALE 1/2 FULL SIZE

PLATE No. 19.


RGE 8 W5M
RGE 7 W5M
PEMBINA
PEMBINA VALLEY
Block #4
Block #3
Block #1
Drayton Valley
Trans Canada
TP 49
TP 48
TP 47
RGE 8
RGE 7
PEMBINA AREA
SHOWING
TOWNSHIP NOMENCLATURE
AND
NUMERICAL BLOCK SYSTEM
REVISED 31/5
MOBIL OIL OF CANADA, LTD.
EDMONTON DISTRICT OFFICE
4
5
6
7
8
9
1
12
10

BIBLIOGRAPHY

1. N. W. Radforth, " Suggested Classification of Muskeg for the Engineer," Engineering Journal November, 1952.
2. Captain S. Thomson, R.C.E., " An Investigation into the Engineering Properties of Muskeg, " Thesis, Department of Civil Engineering, University of Alberta.

Additional Reference Material for Background and Current Information;

3. Lea and Benedict, " Foundation Vane Tester," N.R.C. Tech Memo No. 27.
4. Fenske, "Deep Vane Tests in the Gulf of Mexico, " A.S.T.M. Pam 90 b.
5. Hvorslev, " Subsurface Exploration and Sampling of Soils, " Rotary Vane Tests, page 475.
6. Vey and Schlesinger, " Soil Shear Tests by Means of Rotating Vanes," Proceedings of Highway Research Board, Vol 29 (1949).
7. Hamilton Gray, " Vane Shear Tests of Sensitive Cohesive Soils," Proceedings ASCE July 1955, Vol 81, Paper No. 755.

Appendix No. 1

COMPUTATION OF VANE SIZE

In computing the size of the vane the following points are to be considered.

a) Shearing strength = Torque applied X 5

b) The ratio of height to diameter to be 2 or more.

c) Area upon which the shearing strength acts is side area plus one end area.

From Equation No. 2

$$T = S \times 2\pi r^2 \left(h + r/3 \right)$$

and as $S = 5\ T$

$$1 = 10\ \pi r^2 \left(h + r/3 \right)$$

Trial # 1.

Letting $r = 0.25$ feet then $h = 0.425$ '

$h/D = 0.85$

Trial # 2.

Letting $r = 2\ 1/4$ " then $h = 10.1$ "

$h/D = 2.25$

USE VANE WITH Diameter = 4.5 " and Height = 10.1 "

SUGGESTED CLASSIFICATION OF MUSKEG FOR THE ENGINEER

by Norman W. Radforth

Coverage Type (Class)	Woodiness vs Non-Woodiness	Stature (approx height)	Texture (where required)	Growth Habit	Example
A	Woody	15 ft. or over		Tree form	Spruce, Larch
B	Woody	5 to 15 ft.		Young or dwarfed tree or bush	Spruce, Larch Willow, Birch
C	Non-woody	2 to 5 ft.		Tall grass like	Grasses
D	Woody	2 to 5 ft.		Tall shrub or very dwarfed tree	Willow, Birch Labrador Tea
E	Woody	0 to 2 ft.		Low shrub	Blueberry Laurel
F	Non-woody	0 to 2 ft.		Mats, clumps or patches sometimes touching	Sedges Grasses
G	Non-woody	0 to 2 ft.		Singly or loose association	Orchid or Pitcher plant
H	Non-woody	0 to 4 in.	leathery to crisp	mostly continuous mats	Lichens
I	Non-woody	0 to 4 in.	soft or velvety	often continuous mats sometimes in hummocks	Mosses

APPENDIX NO. 3

COMPONENT PARTS AND PRICE LIST FOR THE ACKER DRILL COMPANY INCORPORATED VANE SHEAR TEST KIT.

Acker Drill Co. Inc., 725 West Lackawanna Avenue,
Scranton 3, Pennsylvania.

Item		Price
1.	1 - 2" Vane - use with 2½" drive pipe	25.00
2.	1 - 2½" Vane - use with 3" drive pipe	28.50
3.	1 - 3 5/8" Vane - use with 4" drive pipe	31.00
4.	4 - Ball bearing guides - 1 for each 25' depth for 2½" drive pipe @ 14.50 ea	58.00
5.	for 3" drive pipe @ 14.50 ea	58.00
6.	for 4" drive pipe @ 18.00 ea	72.00
7.	1 - Thrust bearing guide for use with E or A Drill rods	36.50
8.	1 - Collar with set screws for E or A rods	5.25
9.	1 - Adapter E or A rod to Torque Wrench	8.50
10.	1 - Torque Wrench - 0 to 150 inch-pounds	46.75
11.	1 - Torque Wrench - 0 to 600 inch-pounds	35.75
12.	1 - Coupling for 2½" drive pipe (2½ x 3)	2.50
13.	1 - Coupling for 3" drive pipe (3 x 3)	3.00
14.	1 - Coupling for 4" drive pipe (4 x 3)	3.85
15.	1 - Carrying Case	24.75
	TOTAL	$ 439.35
	Price when complete kit is ordered	$ 396.00

For export add 8% to the above prices.
All prices F.O.B. Scranton, Pa. 1956.

Gross weight 150 lbs. Volume 3 cu.ft.

APPENDIX NO. 4.

THEORETICAL CALCULATIONS OF ANGULAR TWIST IN DRILL STEMS.

From the theory of torsion,

$$\theta = \frac{M_t}{G \cdot I_p}$$

where θ = twist in radians per unit length

M_t = torque

G = Modulus of Rigidity

$I_p = \frac{\pi d^4}{32}$

To express twist as degrees per foot of length using torque in foot-pounds and assuming $G = 12 \times 10^6$ psi, this equation becomes,

$$\theta\ (\overset{\text{radians}}{\cancel{\text{degrees}}}/\text{foot}) = \frac{M_t\ (\text{foot-pounds})}{144(12 \times 10^6) \times \frac{\pi}{32} \times \frac{5^4}{8^4} \times \frac{1}{(12)^4}}$$

which reduces to,

$$\theta = 0.046\ (M_t)\ \text{degrees/foot.}$$

The following table is produced using this formula.

M_t	θ	Total angle of twist in degrees for lengths in feet					
ft.lbs.	degrees/foot	2	4	6	8	10	12
40	1.84	3.68	7.36	11.04	14.72	18.40	22.08
80	3.68	7.36	14.72	22.08	29.44	36.80	44.16
120	5.52	11.04	22.08	33.12	44.16	55.20	66.24
160	7.36	14.72	29.44	44.16	55.88	73.60	88.32

Plate no. 1 to Appendix 4 presents the above table in graphical form on page 76.

Comparison to the values obtained by measurement of the angular twist in the drill stem is shown by the dashed lines.

The discrepancies are due to,

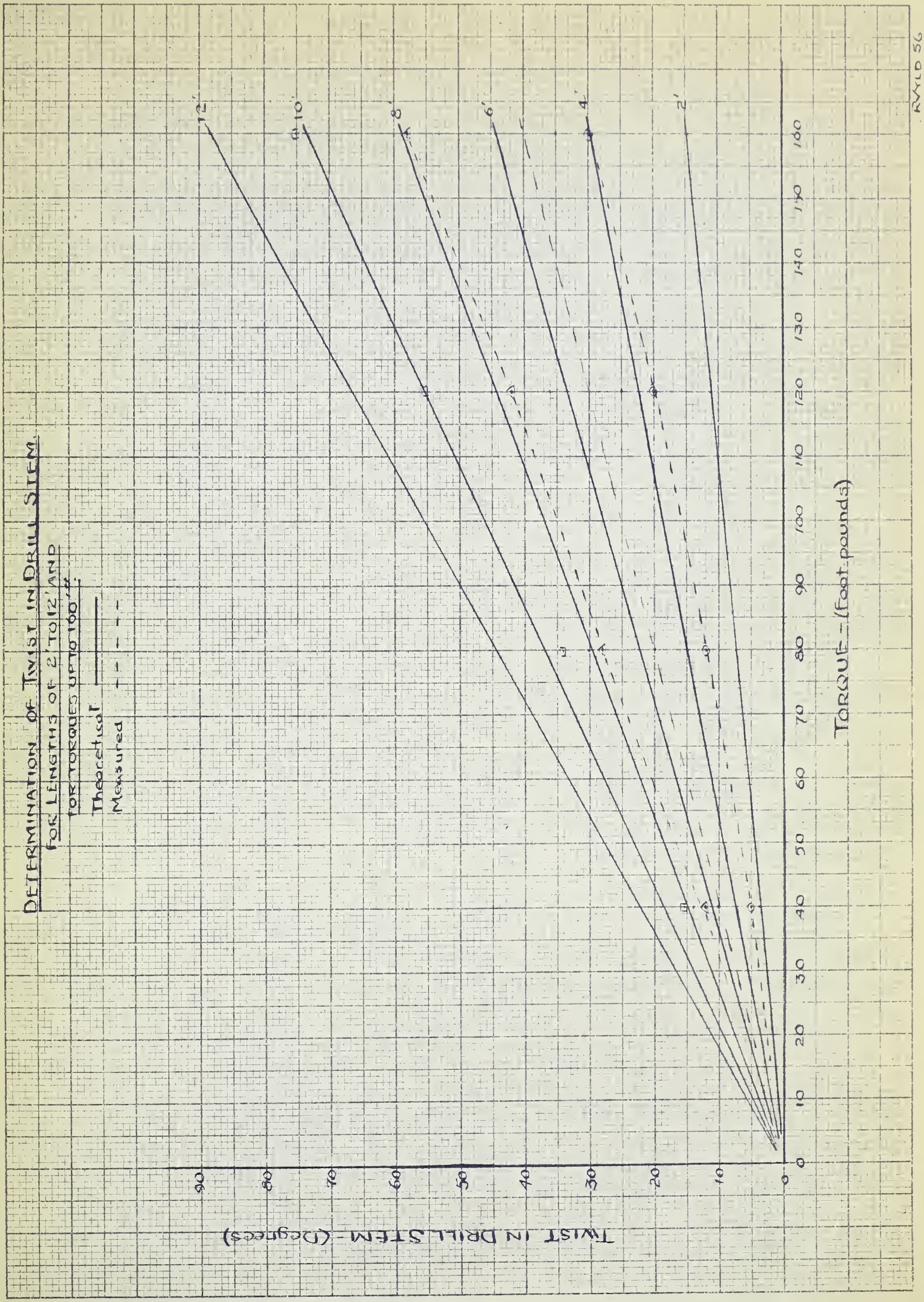
a. assumptions in theory of torsion

b. assuming G as 12 x 10^6 psi

c. the theoretical values do not take into account the enlarged cross-sectional areas at all couplings of the drill stem, which occurred at the 2, 6 and 10 foot lengths and gave a total length of drill stem with increased cross-sectional area of about 27 inches in a ten foot length.

Due to these discrepancies, corrections for angular deformation were taken from the graph as shewn on plate no. 13 page 63, which is plotted from direct measurements.

PLATE I TO APPENDIX 4



DETERMINATION OF TWIST IN DRILL STEM

FOR LENGTHS OF 2' TO 12' AND

FOR TORQUES UP TO 160'#

Theoretical ————

Measured - - - -